GREAT Paper JETS

Norman Schmidt

norman schmidt

great paper jets

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The advice and directions given in this book have been carefully checked, prior to printing, by the Author as well as the Publisher. Nevertheless, no guarantee can be given as to project outcome due to possible differences in materials and construction and the Author and Publisher will not be responsible for the results.

introduction general instructions

Jet engines, first used in military planes, are found today in all manner of aircraft ranging from fighters and commercial transports to sport planes. Some of these "jets" blaze across the sky faster than sound, and fly to the very edge of space. Because of their speed, jets have revolutionized aviation. They have shrunk the world. Now with sophisticated navigational aids to fly high above the weather, jets allow airlines to maintain reliable global schedules to quickly, safely, and comfortably transport thousands of people and tons of freight around the world every day. Jets are a transportation marvel.

The paper planes in this book are modeled after some important jets that have been built. They show how the speed afforded by jet power influenced a new sleek airplane shape. The paper models are constructed out of ordinary index card paper. They are obviously not jet powered but fly as paper gliders.

NOTE The proportions of the airplanes represented in this book have been slightly altered in the paper models to suit the paper medium, and they are not in scale to each other.

A good work area for model building consists of a large flat surface for spreading things out and plenty of light to see what you are doing.

THE PARTS

The planes in this book are constructed with three main parts made up of smaller cut-out pieces, arranged and built up in layers:

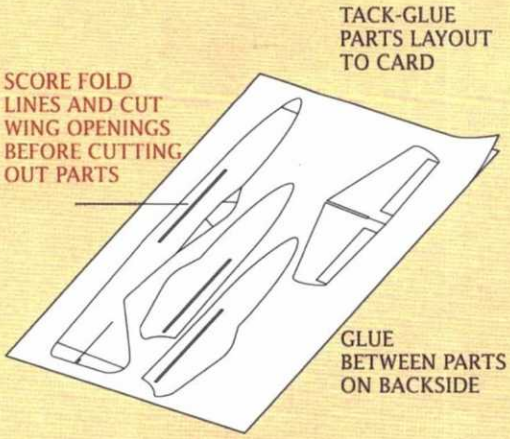
1 fuselage with vertical stabilizer,
2 wings, and
3 horizontal stabilizer.

NOTE model parts are not cut out of the book.

If you have not cut paper with a craft knife, begin by making some practice cuts. In pencil draw some squares, triangles, and circles of various sizes on index card stock and cut them out. For straight cuts use a steel edged ruler to guide the knife; make freehand cuts for curved lines. Always cut by drawing the knife towards you and away from the hand used to hold the paper. Continue to practice until you are comfortable with the tools.

Use a sharp craft knife (an X-acto knife with a #11 blade) on a suitable cutting surface (an Olfa cutting mat). Practice cutting precisely on the line. Always keep the blade sharp.

To camber the wings hold between thumb and forefinger of both hands, as shown. Working from the wing root to the wingtip, gently massage the paper to give the upper surface a convex curvature.



HOW TO PROCEED

FIRST make photocopies

Make *same-sized* photocopies (100%) of the pages containing the parts for building the paper airplanes.

SECOND prepare parts sheets

Cut the **parts layout section** from each photocopy, as indicated on the page, to fit a 5 x 8 inch standard index card. Then tack-glue to the card by applying glue to the areas *between* the parts (**on the backside**) aligning carefully with the edges of the card.

THIRD advanced planning

Before beginning to cut out the parts, score those parts that will need to be bent later, and cut opening slits in fuselage parts. Score and cut precisely on the lines.

FOURTH cut out the parts

Cut out each part shown. This must be done carefully, since the success or failure of every other step depends on accurately made parts.

Cut through both the tacked on guide paper and the card stock underneath. Remove the part and discard the guide paper. This leaves a clean unmarked airplane part, ready for assembly. *Keep track of the parts by lightly writing the part number in pencil on the backside of each part.*

NOTE For all the cut-out pieces, the side that faces up for cutting will be outward or upward facing on the finished plane. This is important for aerodynamic and aesthetic reasons because of the burr on the edges due to cutting.

FIFTH build the fuselage

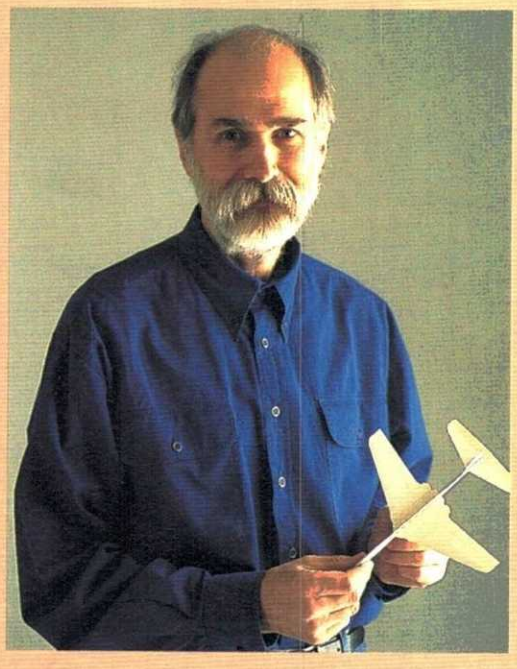
Follow the sequence shown in the diagrams given for each model. Begin with the number one fuselage part, adding the other smaller parts on each side to complete the fuselage. *Align parts carefully.* Take care to position the bent over parts accurately because they are the fastening tabs for wings and horizontal stabilizer.

Stick glue (e.g. Uhu Color Stic), white craft glue, or wood-type model airplane glue can be used. However, it is easier to manage the drying time and reduce warpage with stick glue.

When building up the main parts in layers, apply glue to the entire *smaller* surface to be fastened to a larger one. Press parts firmly together. Continue until the entire main part is completed.

Caution:
To avoid injury,
never fly a paper airplane
toward another person.

The author holding a paper Comet, the first jet airliner. Test flights, straight glides, and games such as flying through hoops and spot landings can be done satisfactorily indoors. High speed and long distance flights must be done in wide open spaces away from obstacles and traffic.



Lay the assembled fuselage flat between clean sheets of paper underneath a weight (some heavy books) until the glue is sufficiently set. This will take between 30 and 45 minutes for stick glue, and several hours for white glue.

SIXTH build the wings

Symmetry is essential for wings. Again, align parts carefully. Special care must be taken in those wings consisting of two halves. Temporarily align the halves using masking tape on the bottom side until the joining piece on the topside is glued in place.

The dihedral angle (upward slanting of wings from center to tips) must be adjusted while the parts are being assembled (before the glue is set). Use the angle guide given with each model for details. If stick glue is used, simply prop up the wings at the tips until the glue has set. If white glue (or model glue) is used, drying the wings is complicated. Some means must be devised to keep each wing from warping while maintaining the dihedral angle.

When the glue is dry add decoration and color to the fuselage and wings, if desired.

SEVENTH put it all together

Apply glue to the bent-over tabs that join the wings and horizontal stabilizer to the fuselage. Align the wings and stabilizers carefully. Press glued parts together. *Adjust placement carefully, viewing the plane from the top, the front, and the back.* **Symmetry and straightness in the completed plane are essential.**

EIGHTH camber the wings

This is a critical step. Cambering the wings gives them their ability to generate aerodynamic lift. Holding a wing at the root between thumb and forefinger of both hands, gently massage the paper to give the upper surface a slight convex curvature or camber. Work carefully from the wing root toward the tip and back again. Make sure the left and right wing have the same amount of camber. Avoid kinking the paper. See the instructions for each model for the proper amount of camber.

NINTH test fly

The paper glider must be well trimmed (adjusted) before it can perform satisfactorily. See pages 36 and 82.

TENTH fly for fun

Paper gliders perform best out-of-doors in a light breeze in wide-open spaces, away from obstructions and traffic.

Messerschmitt Me 262

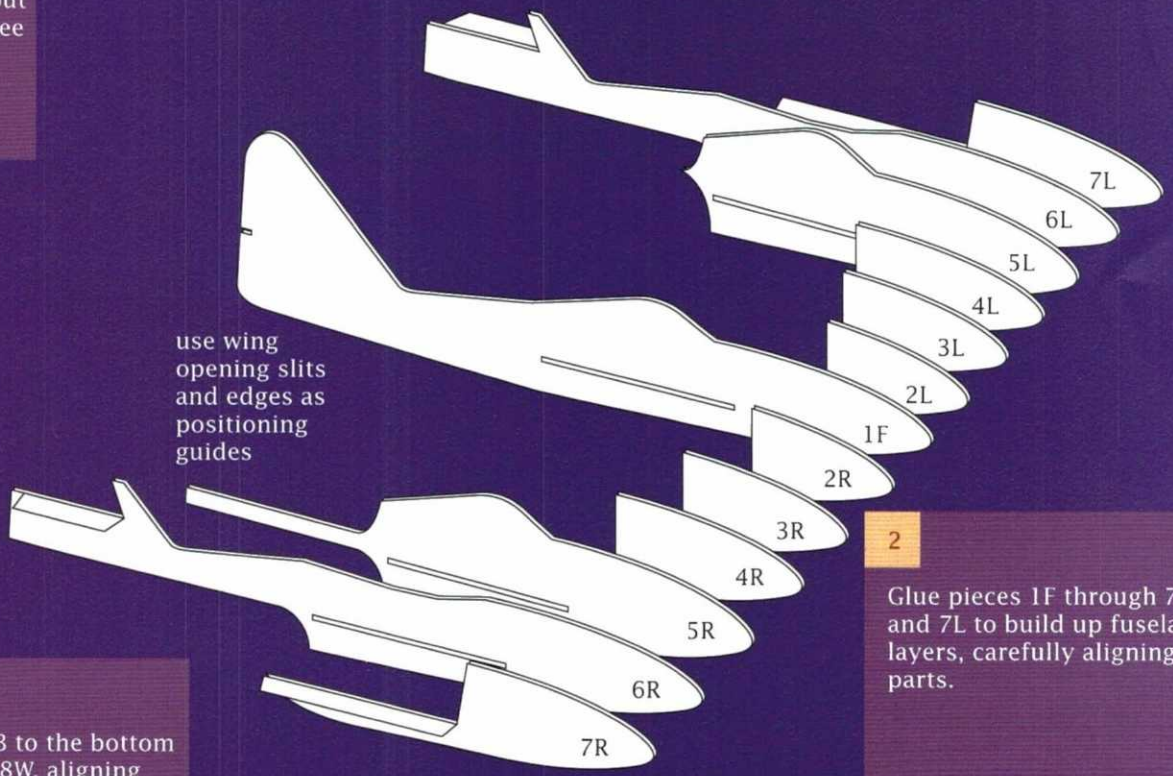
first operational jet

1

Building the Me 262

1

Photocopy the parts layouts for this model. Then cut out and prepare the pieces. (See the general instructions beginning on p 4.)



2

Glue pieces 1F through 7R and 7L to build up fuselage layers, carefully aligning parts.

3

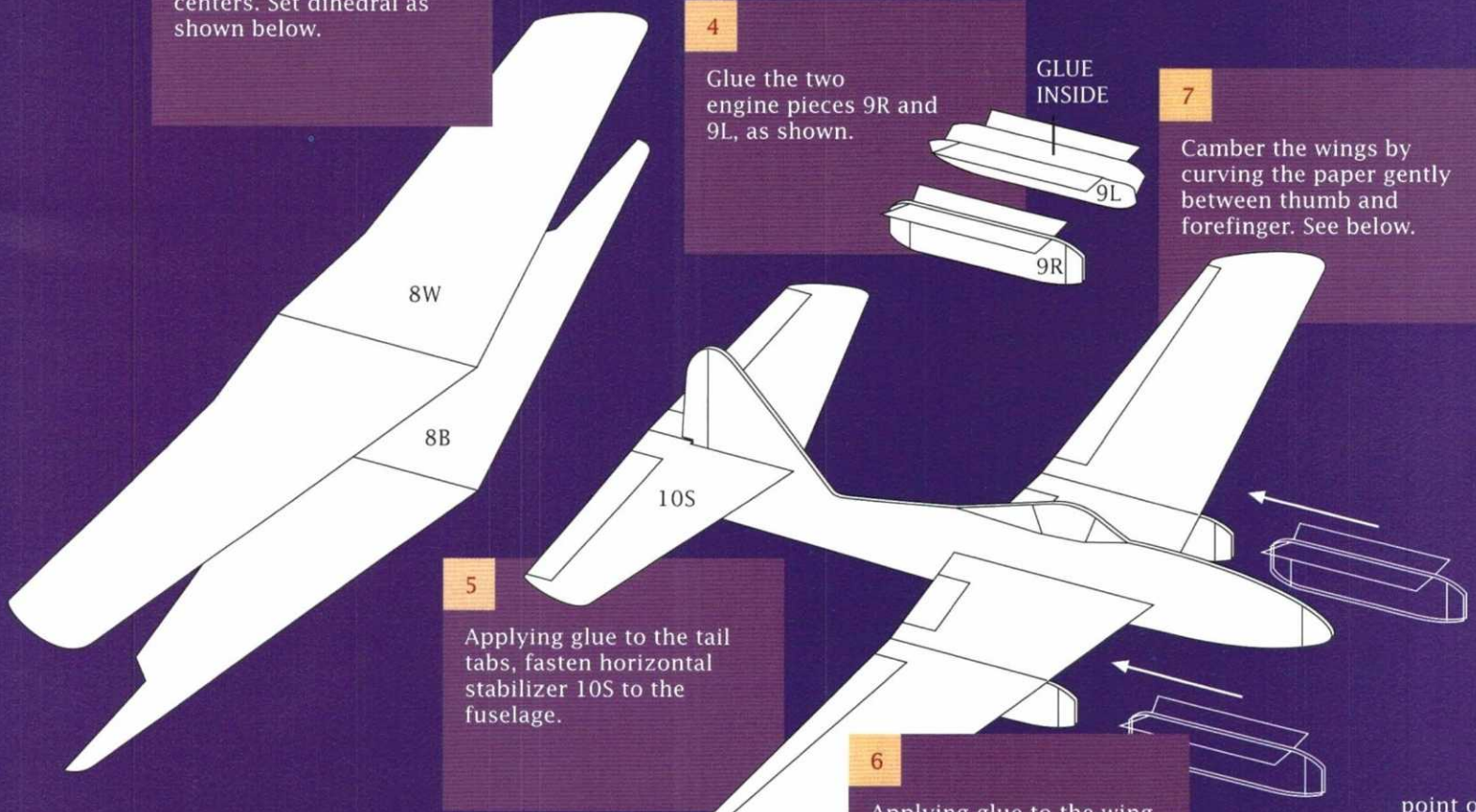
Glue piece 8B to the bottom of wing part 8W, aligning centers. Set dihedral as shown below.

4

Glue the two engine pieces 9R and 9L, as shown.

7

Camber the wings by curving the paper gently between thumb and forefinger. See below.

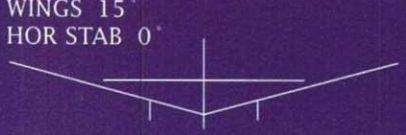


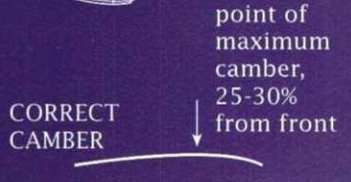
5

Applying glue to the tail tabs, fasten horizontal stabilizer 10S to the fuselage.

6

Applying glue to the wing tabs, fasten wing assembly to the fuselage, aligning center lines. Then glue one engine to the bottom of each wing.





NOTE
- Cut on lines shown in black.
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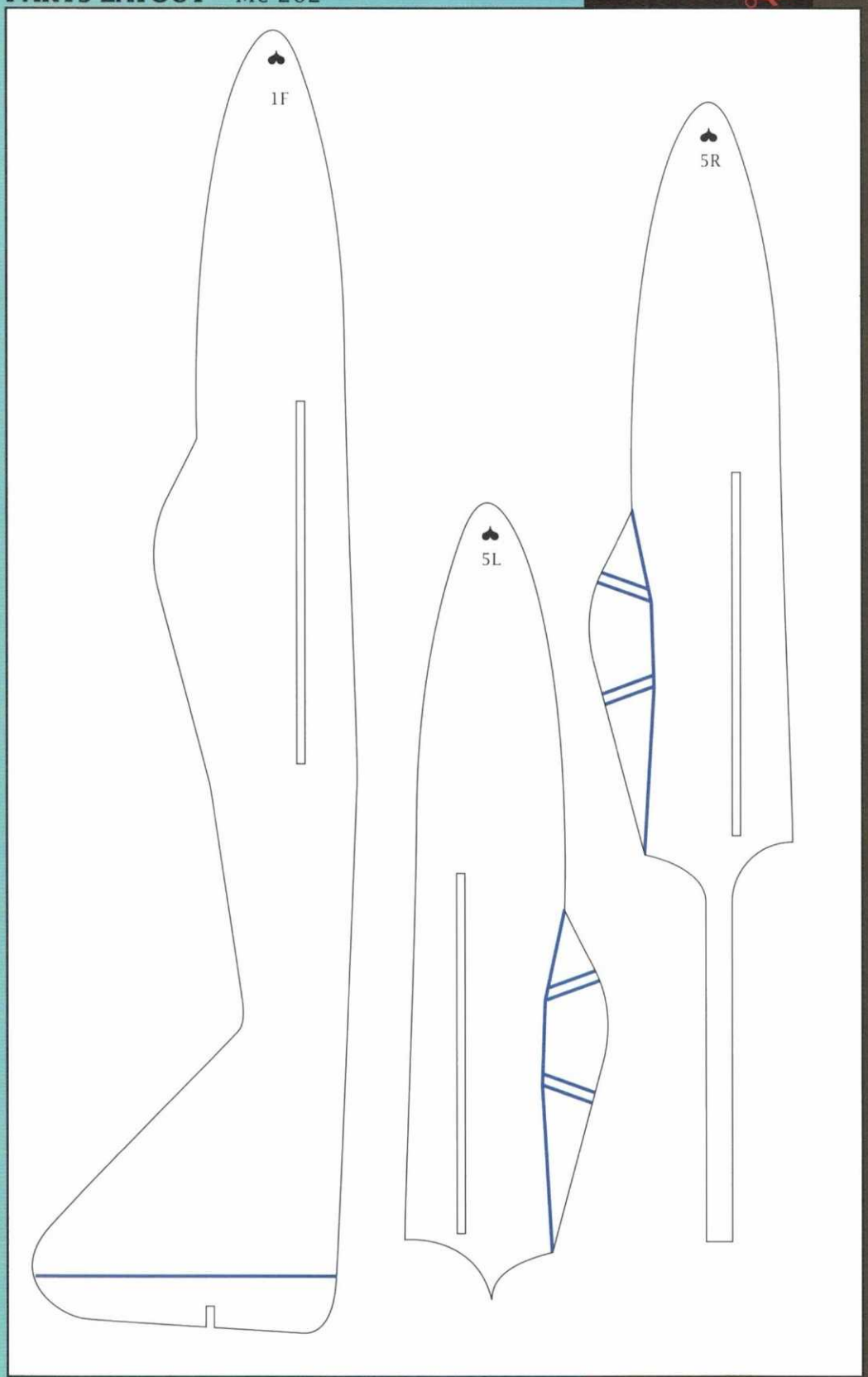
NOTE
CUT OUT PHOTOCOPY ONLY

PARTS LAYOUT – Me 262



the story of jet propulsion

The need for speed first became evident during the Second World War as pilots pushed their planes to the limit, climbing, turning, and diving to maintain advantageous positions. Because the fastest fighters were most likely to be victorious in air combat, and the highest flying bombers were out of harm's way from ground defense, airplane designers tried to squeeze more and more power from the combination of piston engines and spinning propellers in the attempt to create faster and higher flying machines. The quest for speed eventually led to the invention of the jet-propelled airplane. Jets fly very fast.

Most people consider jet power to be an entirely new invention, yet its first demonstration took place more than 2000 years ago. It took all of the intervening years to discover how to put it to practical use.

Consider this background. In the year 100 B.C. an Egyptian inventor named Hero, built a steam jet. He noticed that water boiling vigorously in a kettle caused its lid to lift intermittently, letting out puffs of steam. He created a device to capture the power he saw in the steam. It consisted of a closed kettle fitted with a tube leading to a hollow sphere that was free to spin on the tube. On each side of the sphere were jet nozzles bent in opposite directions. When water

was boiled in the kettle, steam rose through the tube into the sphere where it collected. As pressure in the sphere increased, jets of steam shot from the bent pipes creating a thrusting force, which caused the sphere to spin rapidly.

Over the years various individuals in different places realized, as did Hero, that heated gases generate thrust with enough power to create motion. For example, in 1500 the Italian inventor and artist Leonardo da Vinci, suggested that smoke rising in a fireplace chimney might be captured in some kind of engine. The power of the hot chimney gases could then be used to turn a spit for roasting meat in the fireplace.

Ancient Chinese writings from about the time of Hero describe how eggs could be made to fly by using fire. In *Science and Civilization in China* (Cambridge, 1965, p. 596), J. Needham quotes, "Take an egg and remove the contents from the shell, then ignite a little mugwort tinder (inside the hole) so as to cause a strong current of air. The egg will of itself rise in the air and fly away."

More recent Chinese history records how, in 1232, "arrows of flying fire" were used in war. They effectively frightened the enemy and set fire to their encampments. The arrows were in fact rockets, propelled by a jet of flame escaping from a nozzle in the tail. Soon traders brought these rockets from

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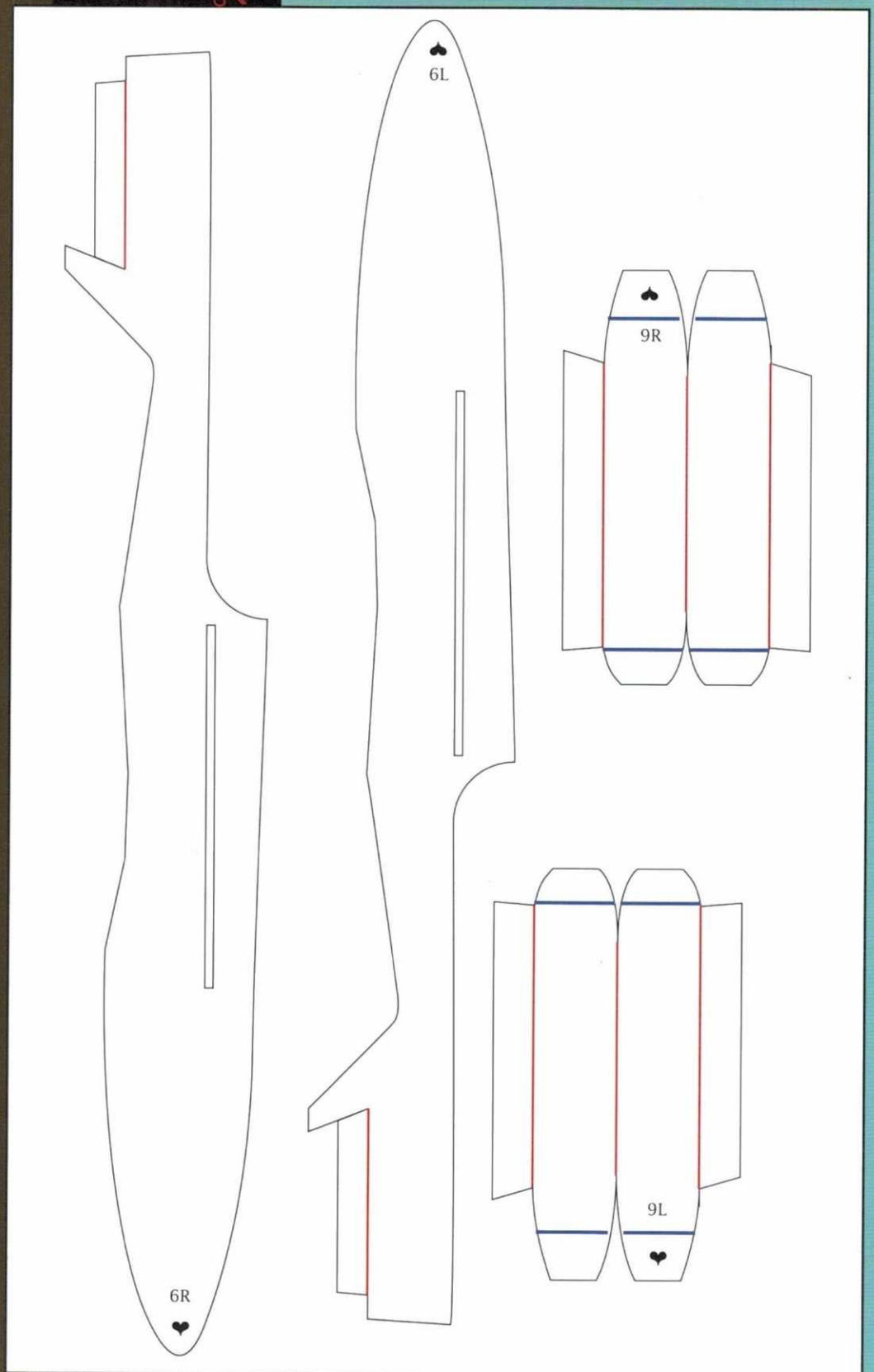

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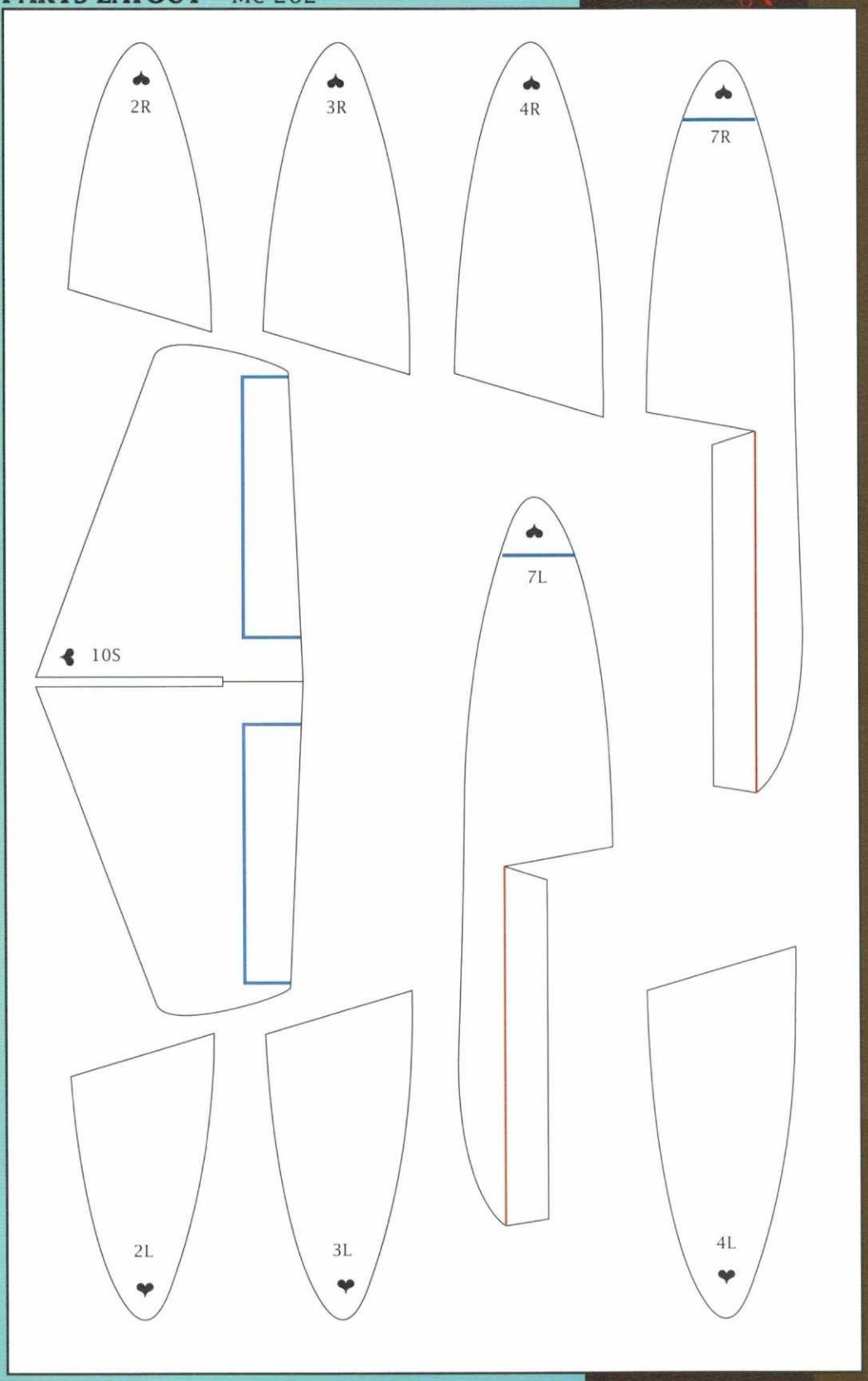
PARTS LAYOUT – Me 262



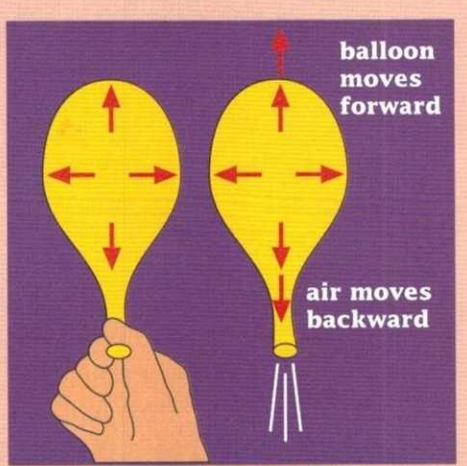
China to Europe. Because of their simplicity jets of this type were built in large numbers before any other kinds. Besides their use in weaponry they were used as fireworks on festive occasions.

Another early example of jet propulsion is that of Ferdinand Verbiest, a Jesuit priest who lived in China in 1678 and built a model jet-propelled carriage. As did Hero's engine, it had a closed kettle and a tube leading to a collector. But instead of jets spinning a sphere, a nozzle came straight from the collector out the back end of the carriage. When water was boiled in the kettle, the thrust of the jet of hot steam escaping the nozzle drove the carriage forward.

FIGURE 1

Action and reaction

As a balloon is inflated, more and more air is squeezed in. The pressure inside is raised. As long as its opening is pinched shut, the pressure inside is equal in all directions. The balloon is stationary. When the opening is released, a jet of air rushes out with force in the direction of the opening. This action has an equal reaction in the opposite direction with enough force to propel the balloon across the room. This is jet propulsion.



THE LAW OF NATURE AND JET PROPULSION

The inventors of long ago did not know how escaping gases generated power. Some believed, wrongly, that the streaming jet somehow pushed against the air to create a forward thrust. It wasn't until 1687 that the scientist Sir Isaac Newton described the principle correctly. This law of nature states that to every *action* there is an equal and opposite *reaction*.

Observe a frog jumping from a branch that is floating in a pond. The leaping *action* of the frog's legs sends it through the air in one direction. But the legs also apply a *reaction* against the floating branch, causing it to move in the opposite direction in the water – action, reaction.

Or take an ordinary balloon. As it is inflated by blowing into it, the air inside becomes pressurized as more and more air is squeezed in. As long as the opening is pinched shut nothing happens. But if you let go, the balloon shoots across the room. Why? As long as the opening is closed the pressure against the inside of the balloon is equal in all directions. But when it is opened a *jet of air* rushes out releasing pressure on that side of the balloon. The rushing jet is an *action* of the air in the direction of the opening. According to the law of nature there must be a *reaction* in the opposite direction inside the balloon with equal force – action, reaction. The balloon shoots across the room with the force of the reaction. The balloon is a simple jet engine.

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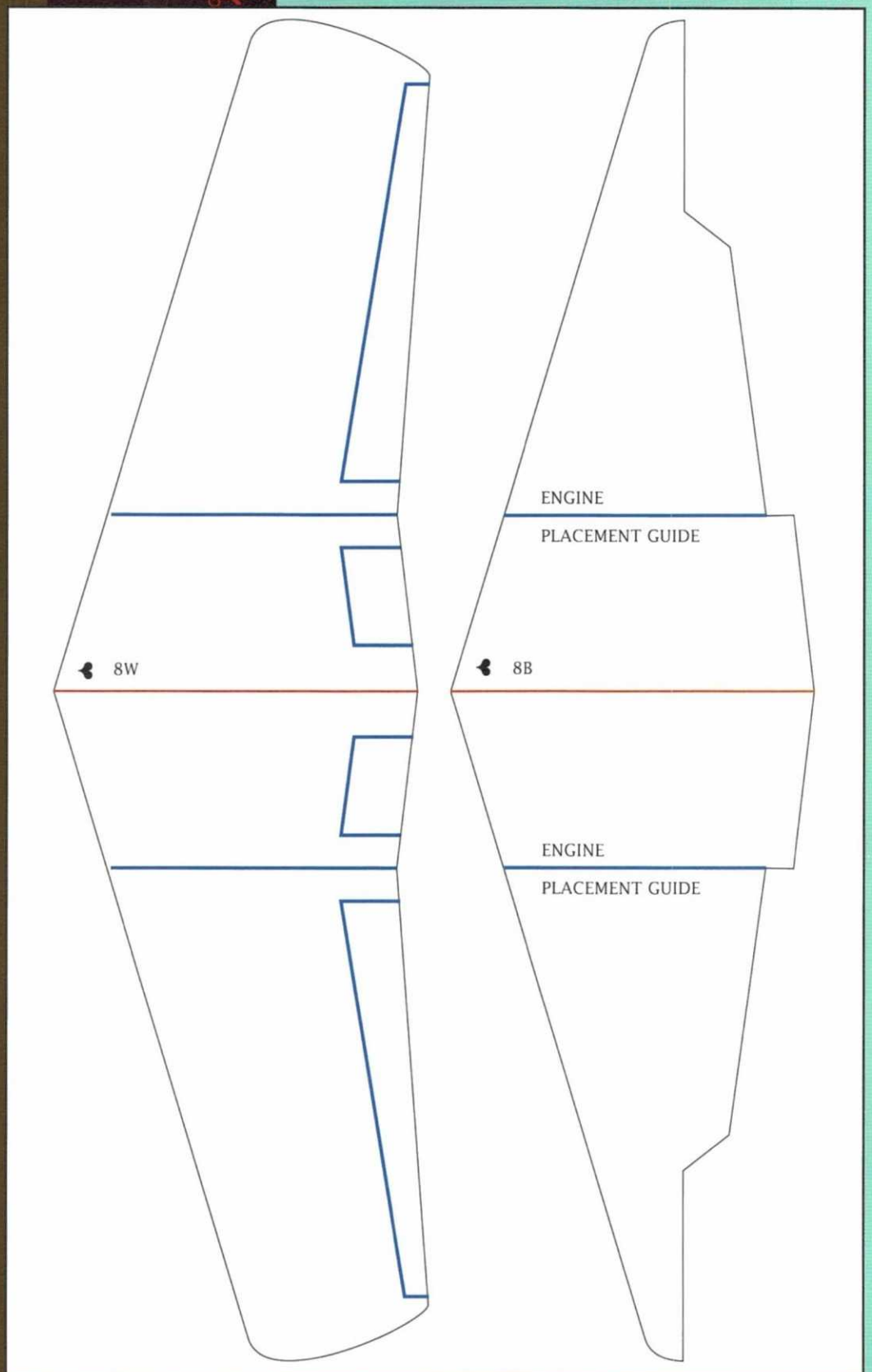


Gloster Meteor F1

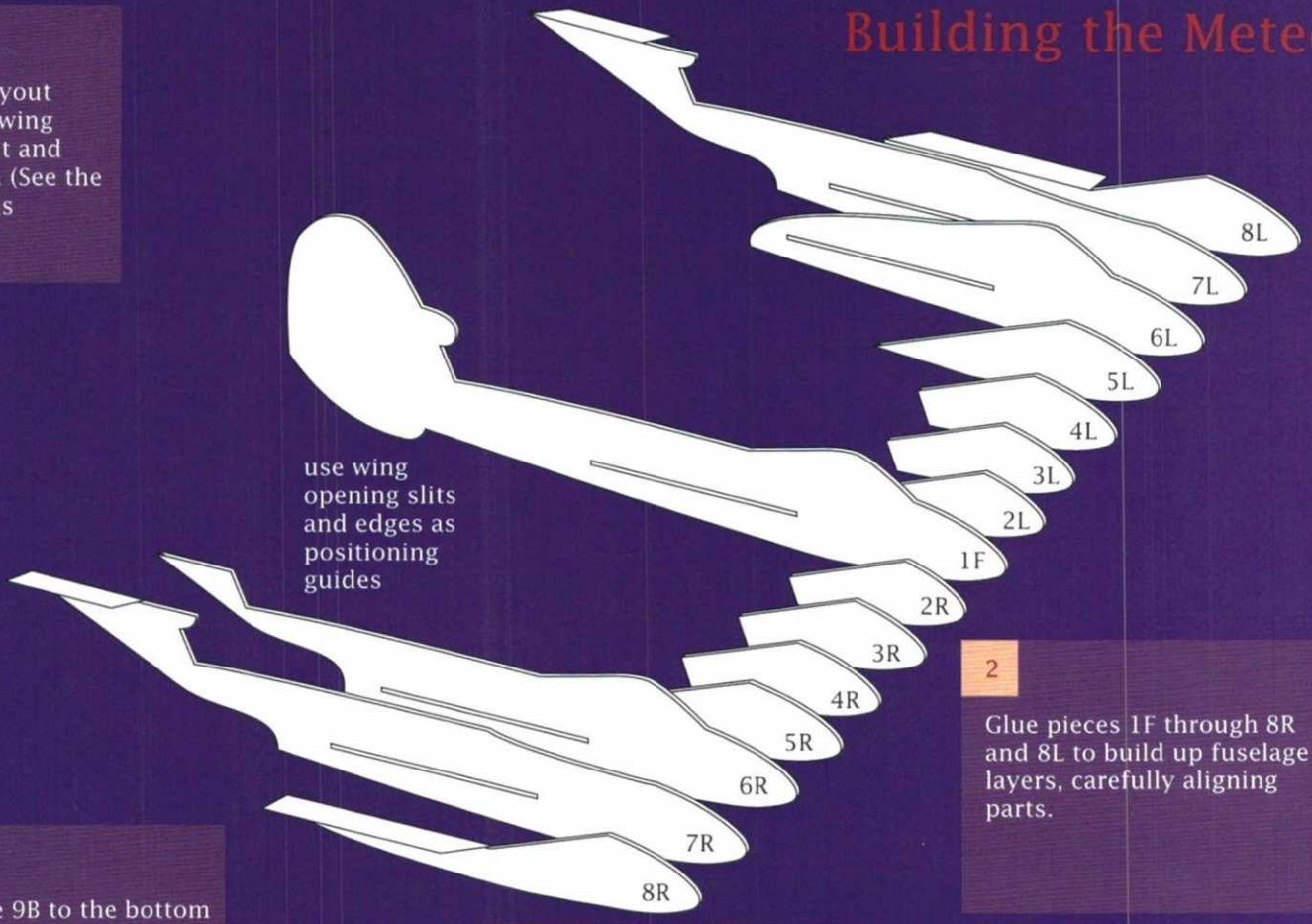
speed record breaker

2

Building the Meteor

1

Photocopy parts layout sheets on the following pages. Then cut out and prepare the pieces. (See the general instructions beginning on p 4.)

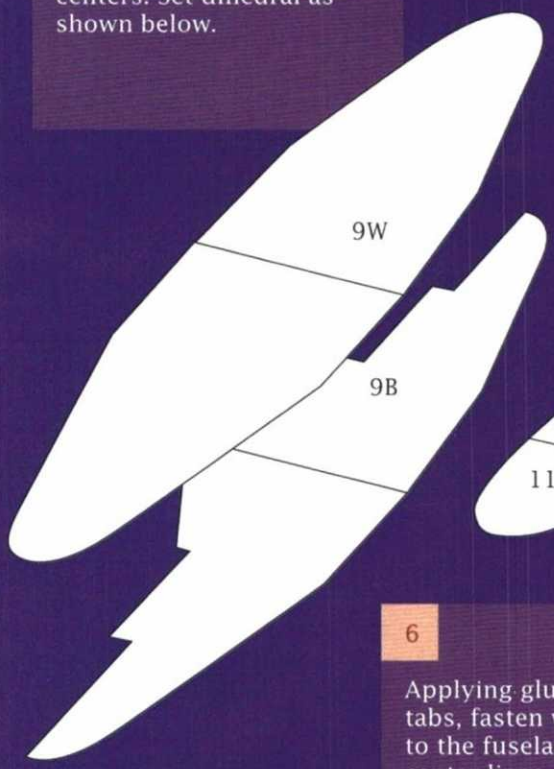


2

Glue pieces 1F through 8R and 8L to build up fuselage layers, carefully aligning parts.

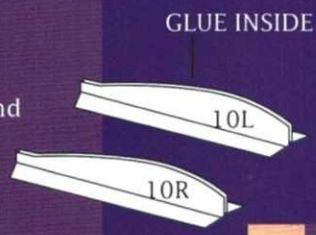
3

Glue piece 9B to the bottom of wing part 9W, aligning centers. Set dihedral as shown below.



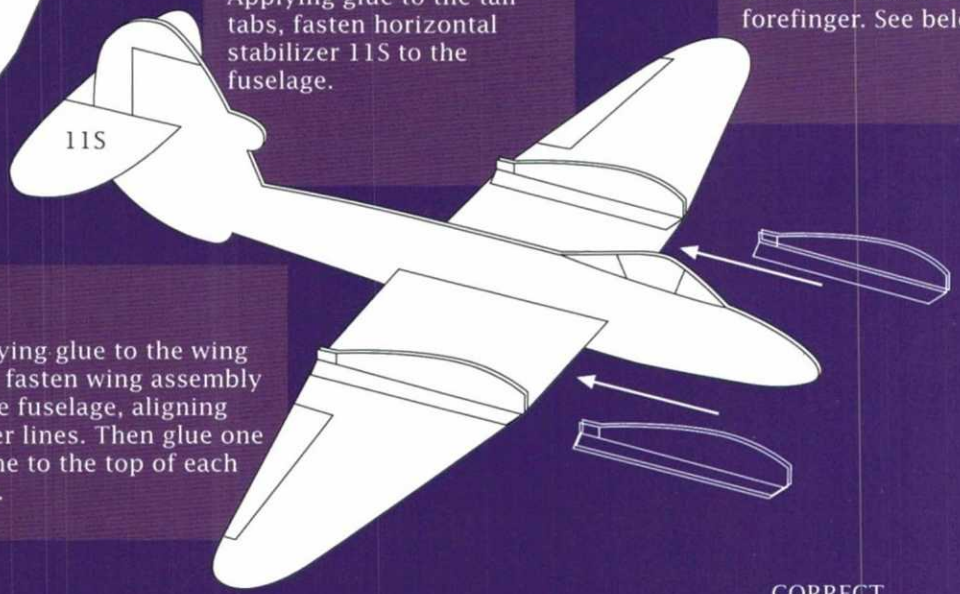
4

Glue the two engine pieces 10R and 10L, as shown.



5

Applying glue to the tail tabs, fasten horizontal stabilizer 11S to the fuselage.



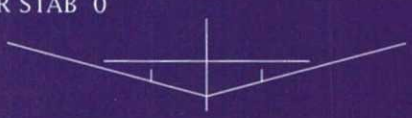
6

Applying glue to the wing tabs, fasten wing assembly to the fuselage, aligning center lines. Then glue one engine to the top of each wing.

7

Camber the wings by curving the paper gently between thumb and forefinger. See below.

WINGS 15°
HOR STAB 0°



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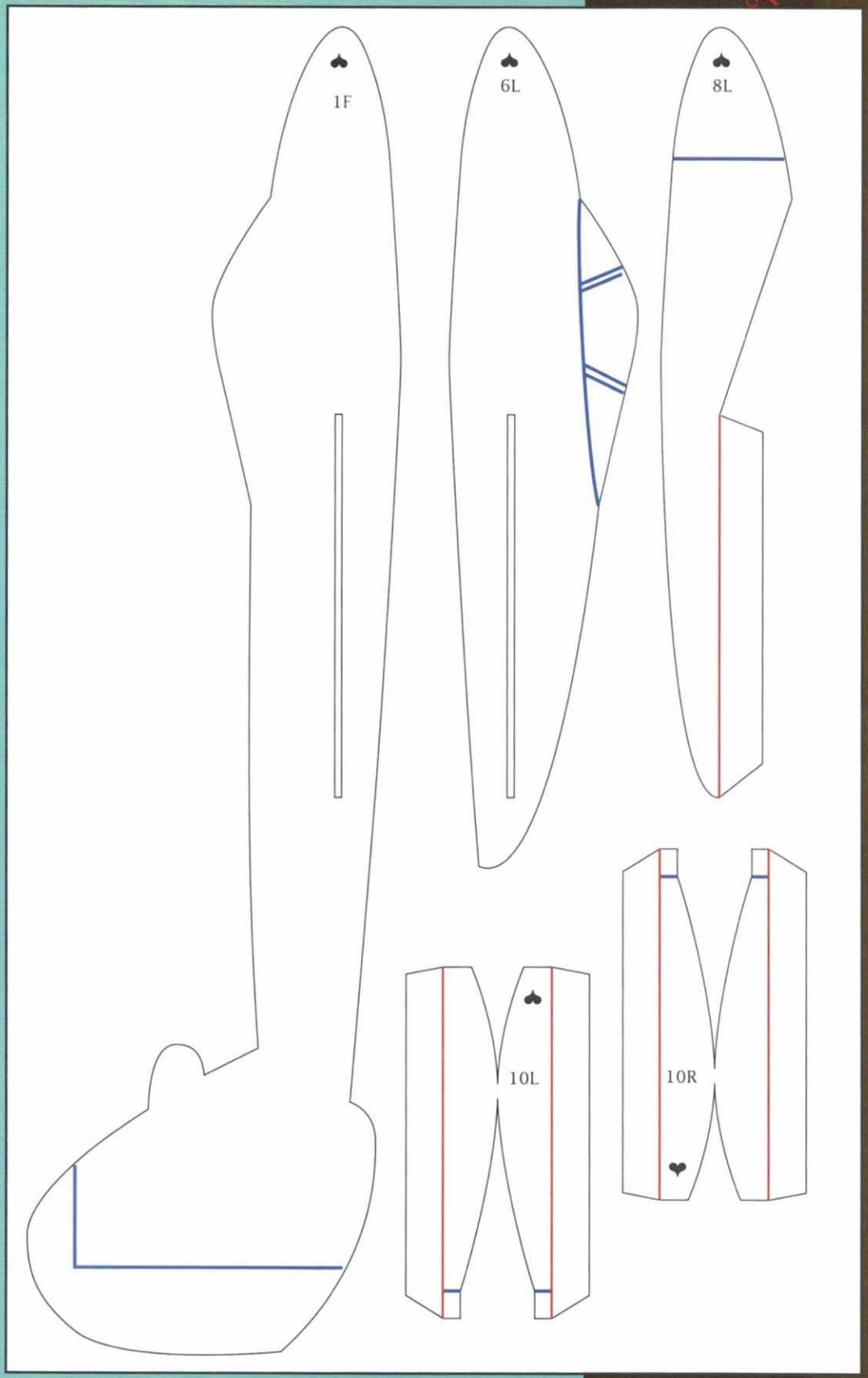
PARTS LAYOUT – Meteor



pioneers of modern jet airplanes

The success of a powered airplane depends on two basic components operating in unison. The first is the airframe, the structure and outer shape of a plane. The airframe determines how an airplane will behave when it moves through air, how it will handle, and how much it can carry. An airframe is designed to operate best within a particular speed and altitude range. The second component is the propulsion system, the means whereby the airframe is driven through the air. The combination of airframe and propulsion system determines how fast and how high an airplane can fly. If not enough power is supplied, the airframe cannot perform as well as possible. It might not get off the ground. If too much power is supplied, the airframe might handle poorly or break up in flight. The two components of airframe structure and propulsion system must be carefully matched for an airplane to be well balanced and controllable under various conditions.

In the time between the two world wars, air races were popular entertainment. Airplane designers everywhere tried to outdo each other in the attempt to win the prestigious races of the day. It was a matter of national pride. It was also important in the development of better airplanes.

The keen competition ultimately resulted in nimble racers that could exceed 400 miles per hour and could turn on a button. These planes had lightweight and strong airframes with efficient wings and were driven by giant piston engines swinging multi-bladed propellers. The giant engines used superchargers (air compressors) to pump additional air into the cylinders to boost power and were very heavy.

When the Second World War broke out, the competition for superior designs moved from the racecourse to the battlefield, and the technology that had been developed for racers was applied to fighters.

Wartime pilots pushed their planes to the limit. One thing noticed was that an overspeed dive introduced strange plane behavior. Sometimes control sticks became immovable or reversed their operation. Other times the airplanes simply went wildly out of control. Such unpredictable reactions were of major concern for airframe designers.

A NEW SOUND IN THE AIR

Always searching for airplane improvements, researchers in different places often come to similar conclusions about the same thing at the same time. Such was the case with jet propulsion. In the 1930s, a small workshop in Britain produced a loud sound not heard before. The same sound was heard in

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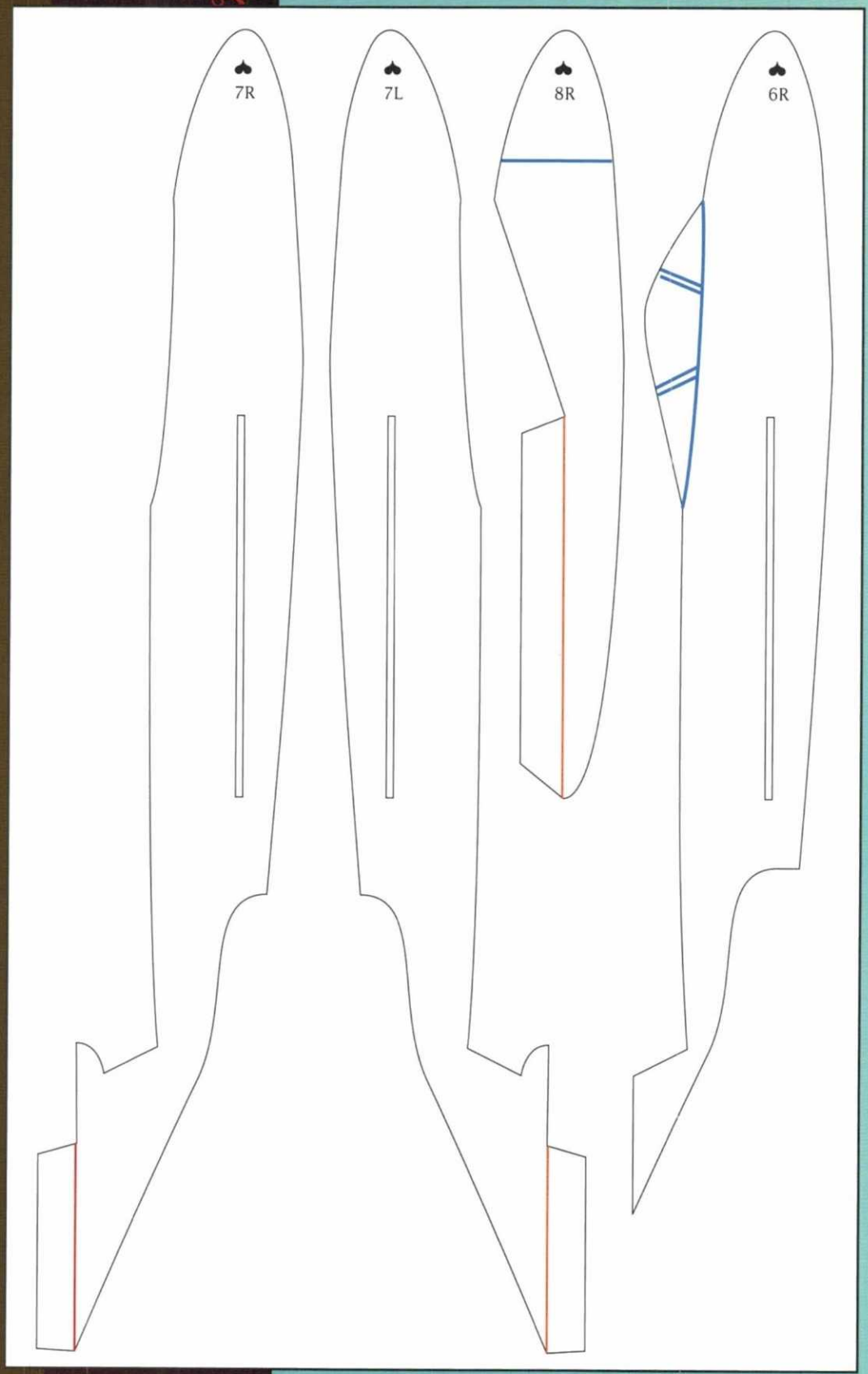

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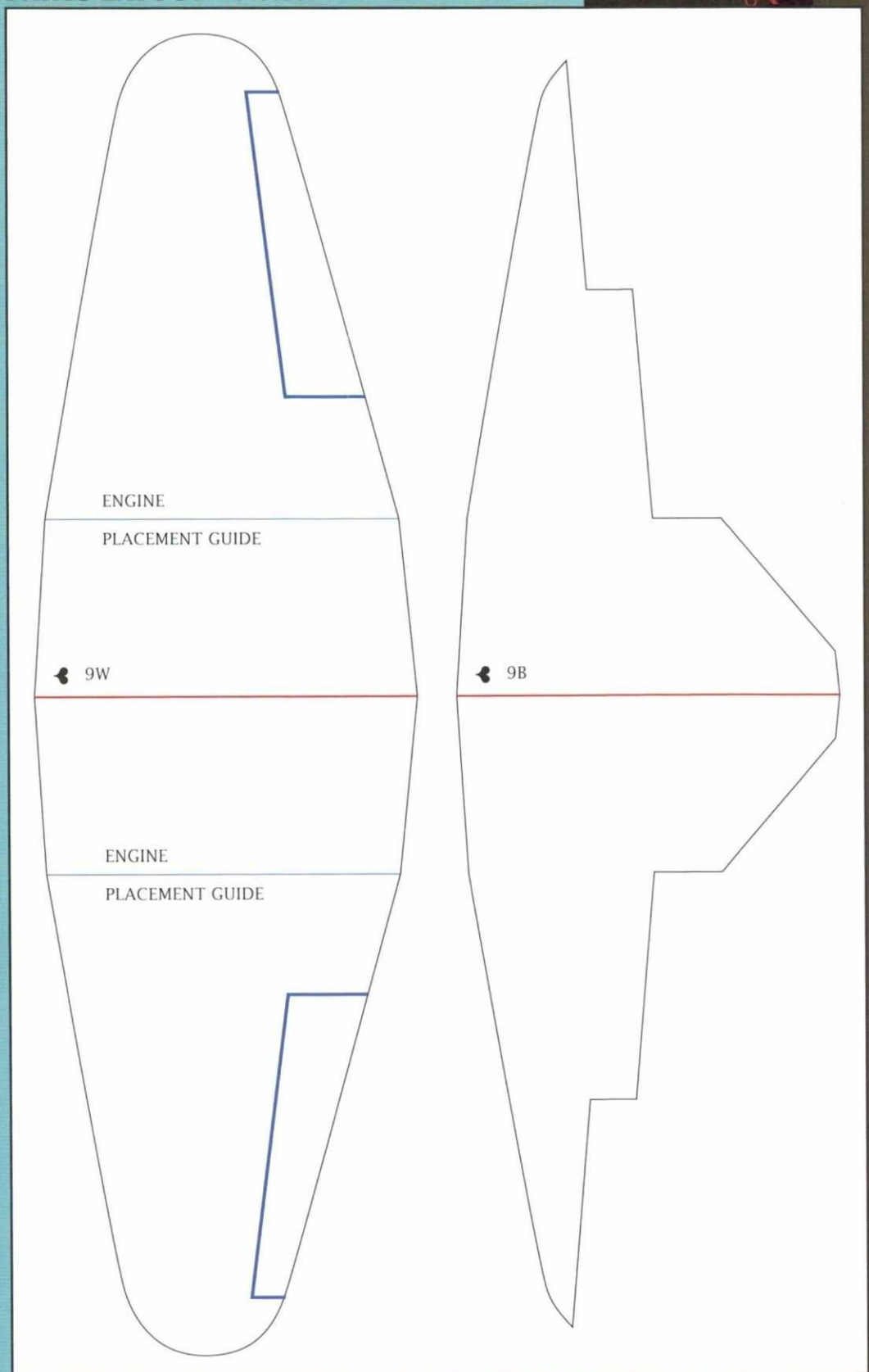

Germany. Two young engineers, Frank Whittle and Hans von Ohain, quite independently had realized that jet power, burning liquid fuel, might result in an engine with fewer moving parts. It would be lighter in weight than a piston engine, making it ideal for aircraft propulsion. On their own, and with little encouragement from big aircraft manufacturers or governments, these dedicated individuals carried out experiments with jet engines.

The basic operating principle of all jets that burn fuel internally is the same. They consist of a cylindrical tube in which fuel and an oxidizer are mixed and ignited. The resulting combustion greatly expands the volume of the gases, which shoot backwards out the exhaust pipe. The action of the jet of hot gases leaving the rear of the engine causes an equal reaction in a forward direction, which is the engine's thrust.

Both engineers realized that for such a jet to work satisfactorily in an airplane, and burn with enough vigor to produce thrust from a standing start, huge amounts of oxygen-rich air would be required in a steady supply. This meant that the air feeding the flame would have to be pressurized before being mixed with fuel. They both knew that this was possible only if the engine had an air compressor ahead of the flame. The compressor,

in turn, could be driven by the thrust of combustion through a turbine located behind the flame and ahead of the exhaust pipe. This idea was not completely new, since these compressors were not unlike those found in the giant supercharged piston engines. This arrangement – compressor, combustion chamber, turbine, jet nozzle – was the magic formula for jet power that the engineers had simultaneously discovered. The new sound was the whine of the turbine and the roar of the jet flame. It was the turbojet. See p 76.

Few people, however, believed that these loud engines would ever amount to anything. The main problem was that jets run extremely hot and no materials existed that could withstand the heat for any length of time. The engines disintegrated after running only a short while.

As the war progressed, the demand for speed in the air increased. Speed meant superiority. Famous air battles, such as the Battle of Britain, had been won, in part, because of the superior speed and turning ability of fighter planes. Their agility came from perfectly matched airframes and propulsion systems. Although more speed was required, designers knew that no more speed or power could be squeezed from existing airframes or engines. The existing large supercharged piston engines were becoming too complicated to be practical, and propellers could not move

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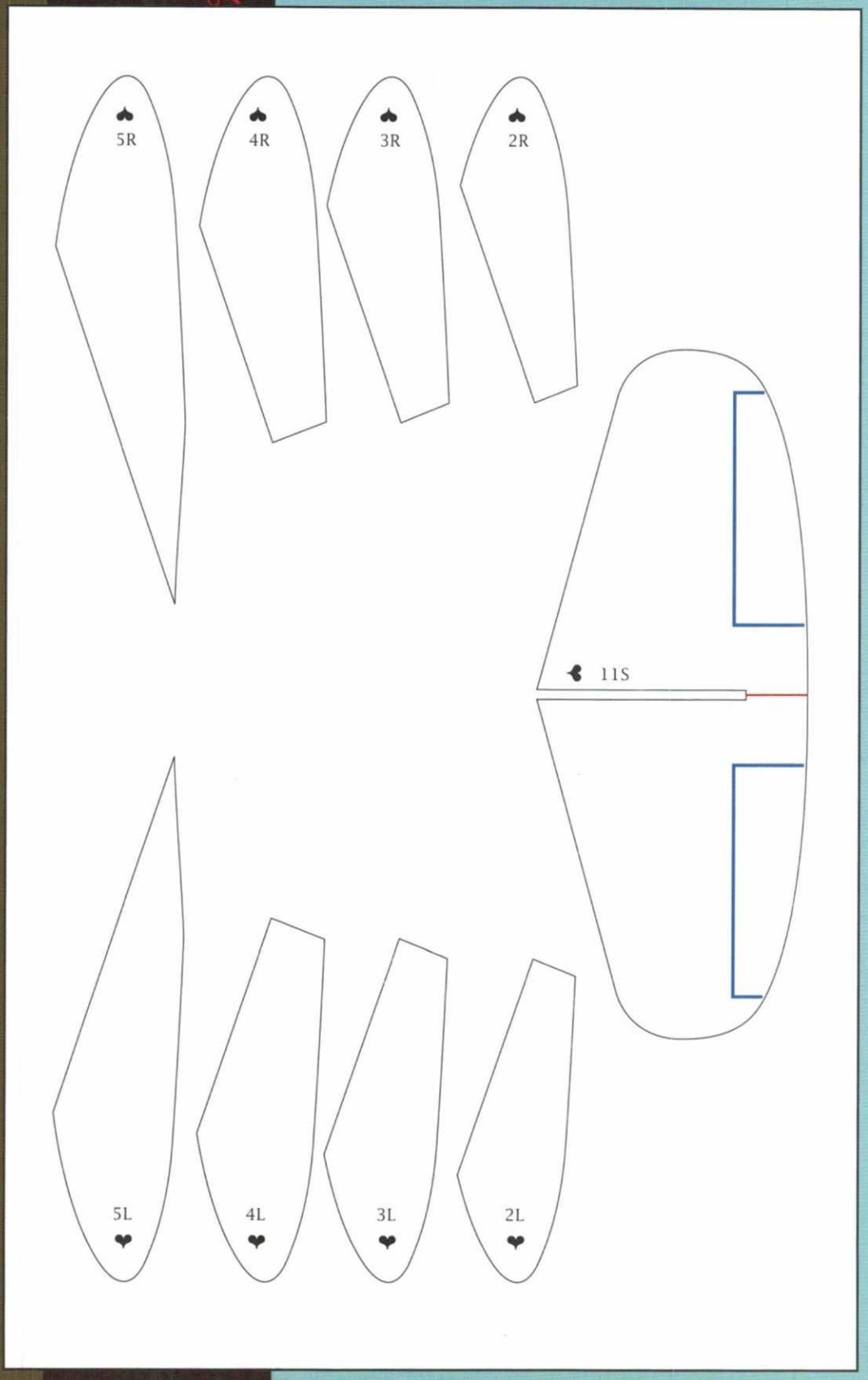
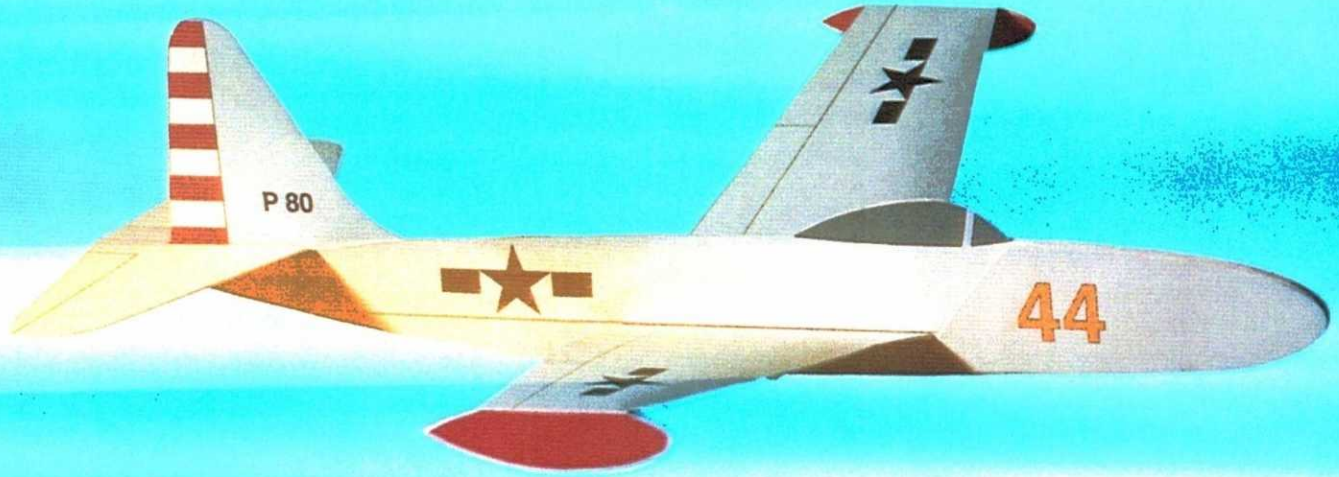
PARTS LAYOUT – Meteor



Lockheed P-80 Shooting Star

the long lived jet

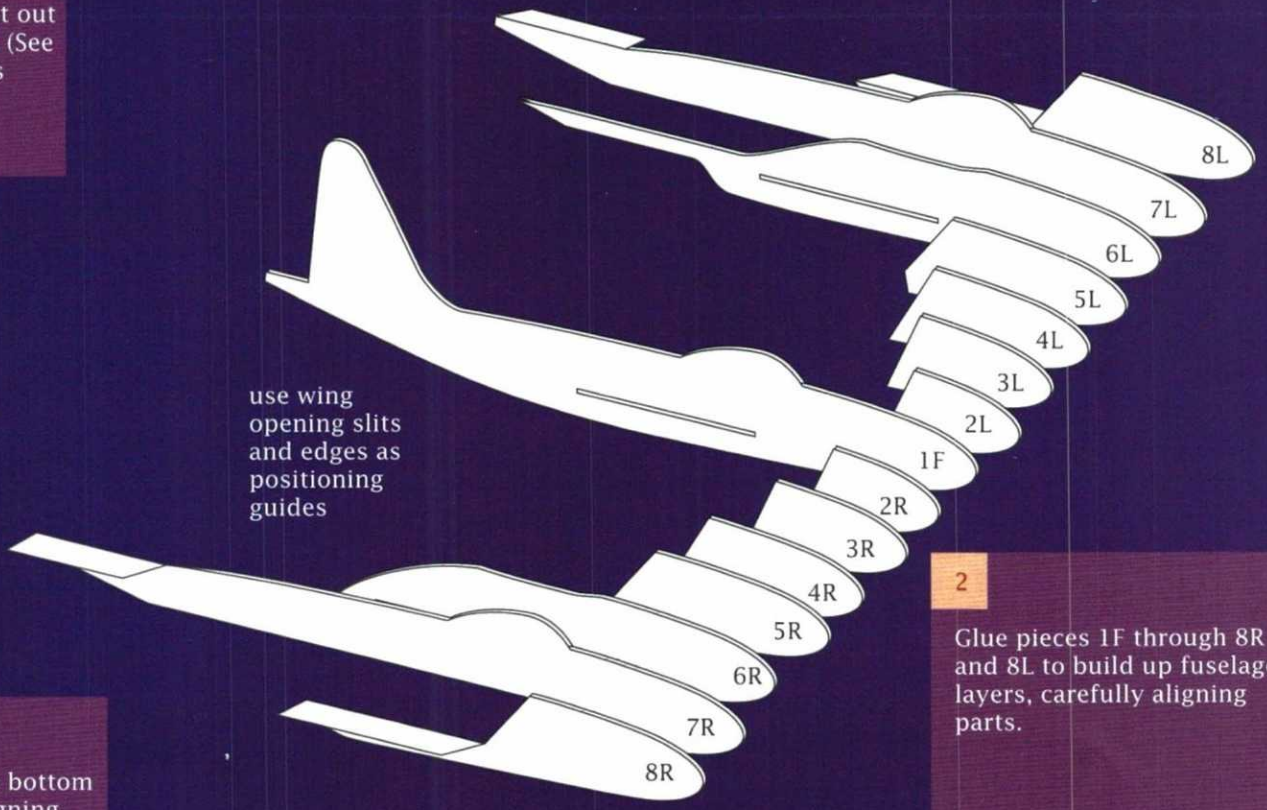


3

Building the P-80

1

Photocopy the parts layouts for this model. Then cut out and prepare the pieces. (See the general instructions beginning on p 4.)



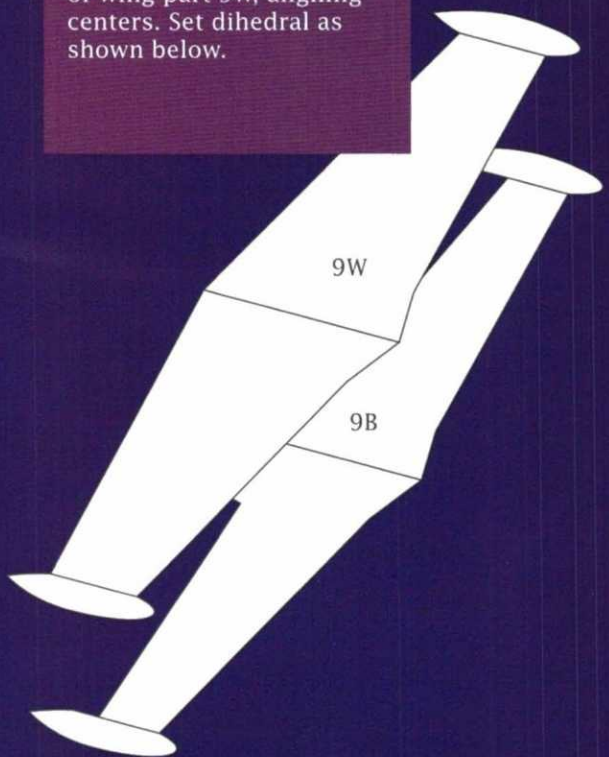
use wing opening slits and edges as positioning guides

2

Glue pieces 1F through 8R and 8L to build up fuselage layers, carefully aligning parts.

3

Glue piece 9B to the bottom of wing part 9W, aligning centers. Set dihedral as shown below.



4

Applying glue to the tail tabs, fasten horizontal stabilizer 10S to the fuselage.

6

Camber the wings by curving the paper gently between thumb and forefinger. See below.

5

Applying glue to the wing tabs, fasten wing assembly to the fuselage, aligning center lines. Then bend wing tip tanks down so that they are vertical.

WINGS 15°
HOR STAB 0°

NOTE
- Cut on lines shown in black.
- Score lines in red.
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- Indicates the front edge of the piece.

NOTE
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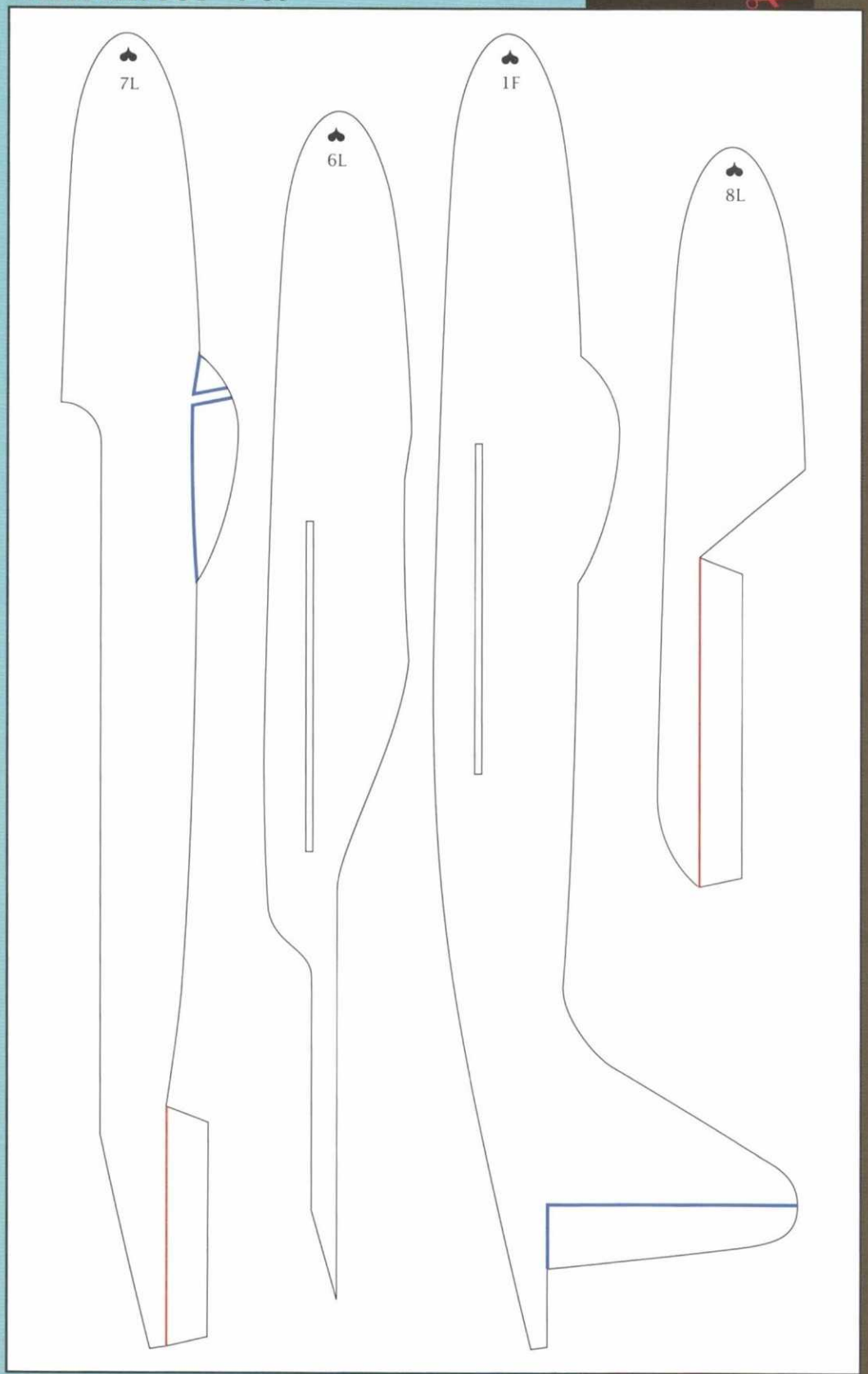
PARTS LAYOUT – P-80



any more air, especially at high altitudes where there was less air to move. Besides, at very high speeds pilots could not control planes with the existing airframes. Wartime designers knew that an end had been reached in traditional aircraft technology and a new approach was needed. Whittle and von Ohain believed the answer to more power lay in jet propulsion. Airframe design was a separate problem that others needed to solve.

FIRST OPERATIONAL JETS

The first jet engines were cranky and unreliable. They burned huge amounts of fuel for their power, and had a service life measured only in minutes before they disintegrated. Jets could be of no use until heat tolerant metal alloys were developed. Because of the wartime demand for rapid advancement, these were forthcoming, and by using them, both engineers were able to run their jets for several hours at a time. Because of this both men convinced their governments to back jet research.

Thereafter development was rapid and jet propulsion systems of various kinds appeared. Research teams were established. In both Britain and Germany various experimental jet-powered planes were tested with increasing success.

By 1944 jet engines were reliable enough to move from the

laboratory to the battlefield. A Junkers turbojet engine was fitted to a Messerschmitt airframe. The plane was the Me 262. **(#1, p 6.)** Soon thereafter in Britain a Rolls-Royce turbojet was installed in a Gloster – the Meteor F1. **(#2, p 12.)** The results were spectacular. The planes were fast. The Me 262 flew a full 100 miles per hour faster than any piston powered plane. The Meteor was not far behind. Both turbojet fighters were built in quantity but never met in battle. The Me 262, the first operational jet, was considered the superior machine.

Rocket engines, too, were used. See p 73. Heinkel built the He 176 rocket-powered fighter, which saw limited service as a defense against Allied heavy bombers. The problem with rockets, the simplest jets, was that all their fuel burned up in only minutes. They were better suited to rocket-propelled weapons, which were in use on both sides by war's end. Rocket power was also used to boost a variety of planes into the air when heavily loaded. Once airborne their regular engines took over.

One jet research team, led by Paul Schmidt, conducted experiments with pulsejet engines. See p 75. The pulsejet was much simpler and lighter than the turbojet, but inefficient by comparison. However, it had a longer burn time than rocket engines, making it useful for a certain kind of aircraft. Towards the end of the war, when most

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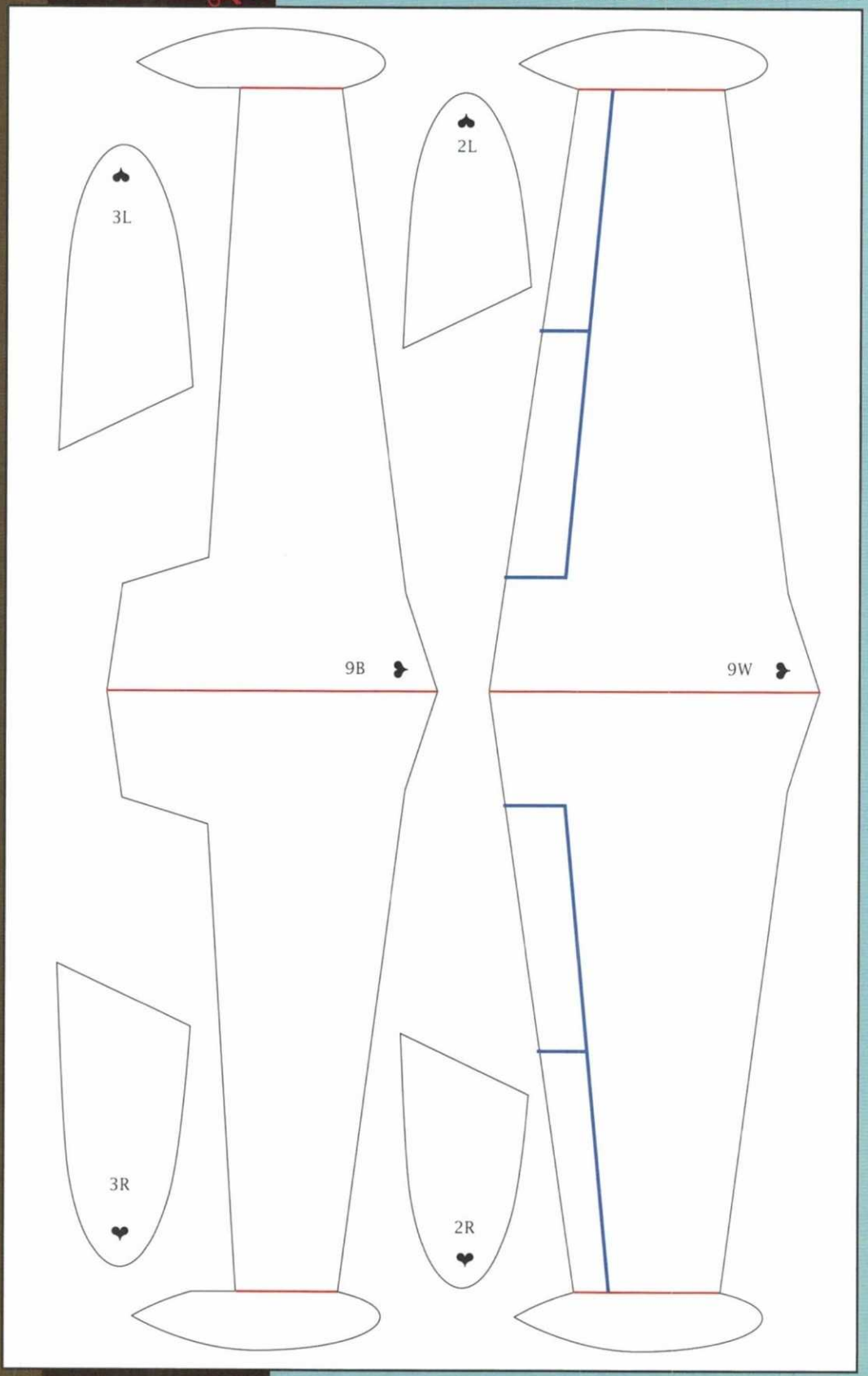

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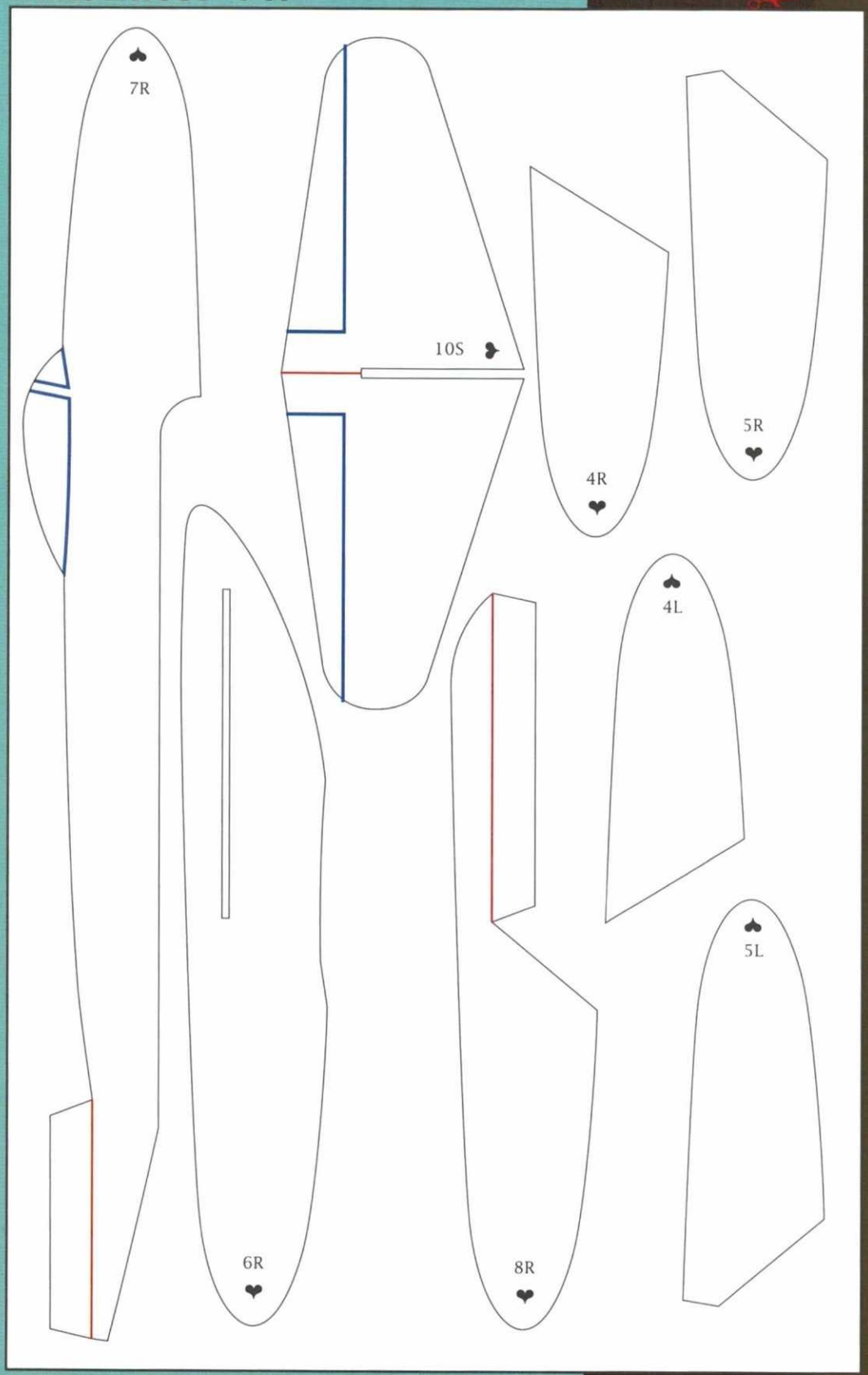
PARTS LAYOUT – P-80



of the German airforce had been destroyed and they had few bombers and fewer pilots in the air, German engineers built a small airframe carrying a single bomb, powered with a pulsejet engine, known as the V-1 Buzzbomb. It had no pilot and was guided by a magnetic compass and clock mechanism. The pulsejet's loud stuttering roar terrified people even before the bomb exploded. Under circumstances of dwindling resources, it was a simple way of retaliating. It had just enough range to reach London from mainland Europe before running out of fuel. Many of these flying bombs were intercepted by the fast Meteor F1s, which marked the first jet-to-jet encounters.

By this time the war was nearly at an end. Of the various turbojet, pulsejet, and rocket-powered craft built by Germany, numbering more than one thousand, only a few ever saw service because there was little fuel to power them.

The demands of war had made jet power practical, even though it had come too late to influence air superiority. But its merits had been clearly demonstrated and the stage was set for this power to be applied widely. After the war, all German technology fell into the hands of the Allies, including their technology developed for jets, resulting in a rapid worldwide application of jet propulsion.

Mikoyan-Gurevich MiG-9

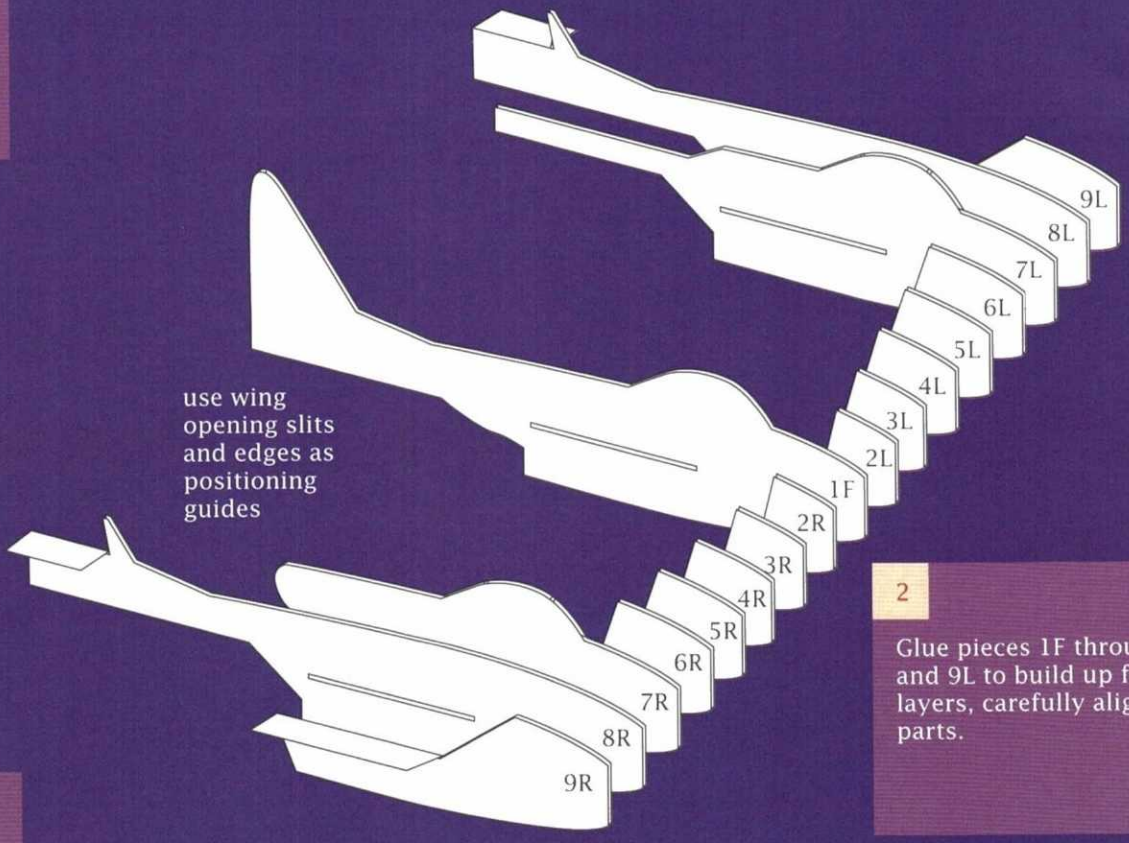
first Russian Jet

4

Building the MiG-9

1

Photocopy the parts layouts for this model. Then cut out and prepare the pieces. (See the general instructions beginning on p 4.)



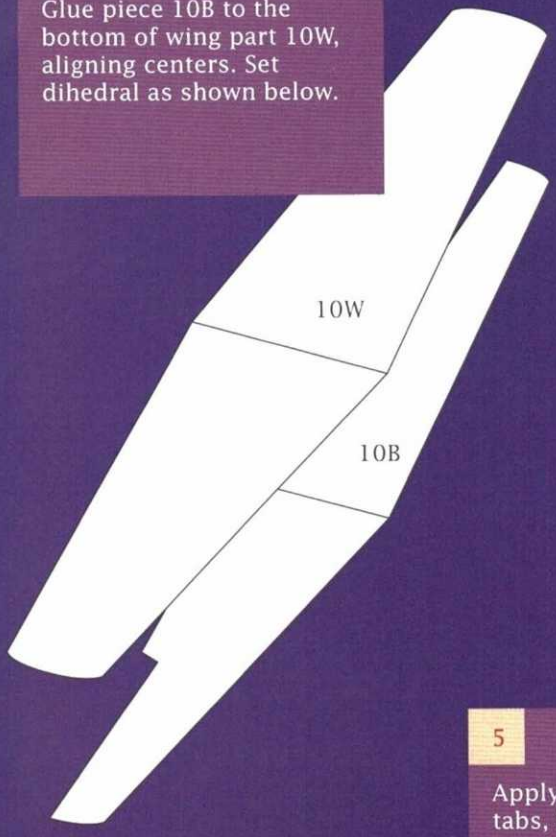
use wing opening slits and edges as positioning guides

2

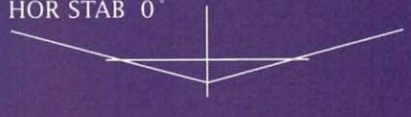
Glue pieces 1F through 9R and 9L to build up fuselage layers, carefully aligning parts.

3

Glue piece 10B to the bottom of wing part 10W, aligning centers. Set dihedral as shown below.

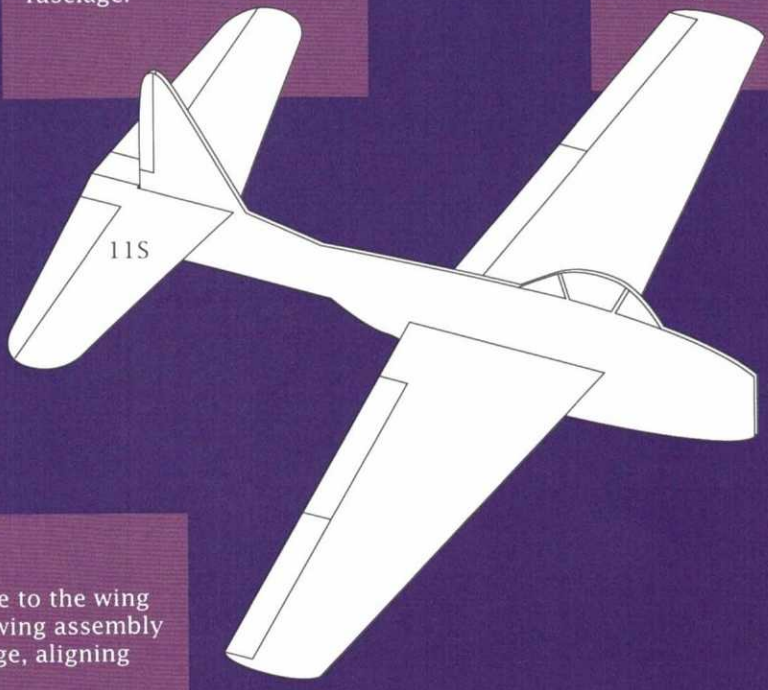


WINGS 15°
HOR STAB 0°



4

Applying glue to the tail tabs, fasten horizontal stabilizer 11S to the fuselage.



5

Applying glue to the wing tabs, fasten wing assembly to the fuselage, aligning center lines.

6

Camber the wings by curving the paper gently between thumb and forefinger. See below.

CORRECT CAMBER

point of maximum camber, 25-30% from front

the shape for high speed

All flight involves the creation of two forces by artificial means to oppose two forces occuring naturally — the force of *lift* must be created to counteract the earth's *gravity*, and the force of *thrust* to oppose air *resistance*. The new jets had plenty of power to overcome air resistance, with early models already matching the most powerful piston engines. The problem was that at very high speed air began to behave differently when flowing around solid objects than it did at low speed, and no one knew exactly what was happening. It was soon discovered how much the shape of an airframe determines airflow. The high speed of jets called for new and different shapes in airplanes.

SHAPE AND FLIGHT

To work, aircraft wings must alter air pressure. They do this in two ways.

First, as they move forward wings slice the surrounding air into two layers, one above and one beneath the wings. Both layers are made up of the same number of molecules. If the wing has a curved upper surface, the molecules moving across the top surface have farther to travel than the ones underneath. As they try to maintain their position in relation to the rest of the air molecules, they become spaced farther apart and their speed increases so that when they reach the back edge of the wing,

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NOTE
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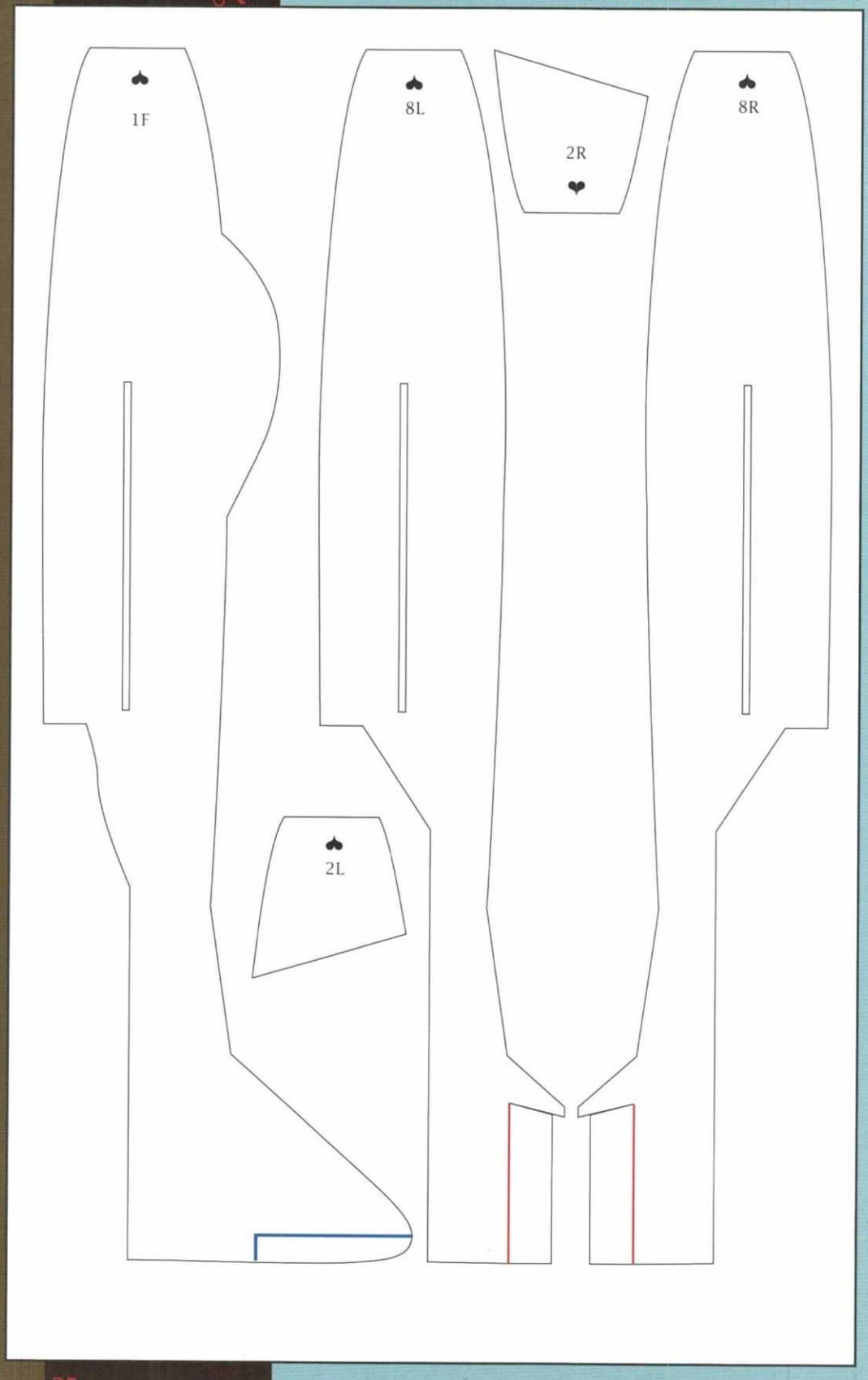
PARTS LAYOUT – MiG-9



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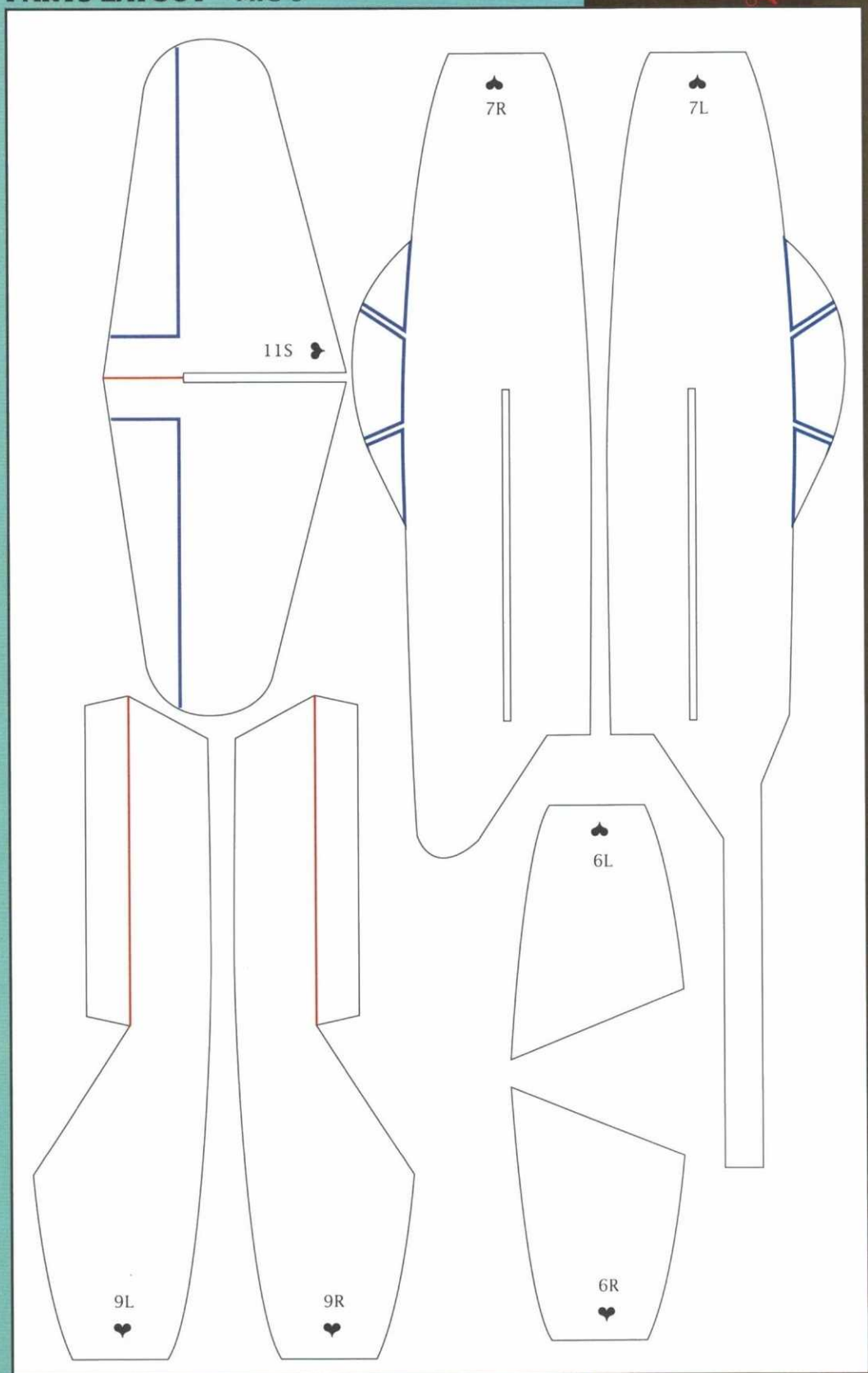


they again match their position with the lower molecules. The faster moving and more widely spaced molecules exert less pressure downward than the slower moving and more closely spaced lower molecules do upward, creating a pressure differential. The reduced pressure above the wings creates suction, much like a vacuum cleaner does. The air underneath pushes the wing into the area of reduced pressure, and the aircraft is buoyed up as it moves forward, counteracting gravity.

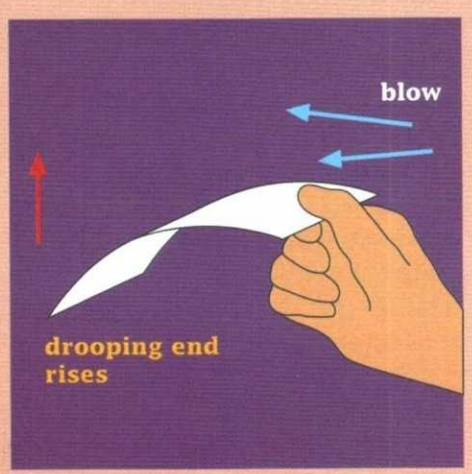
Second, if the leading edge of the wings is raised slightly, allowing air molecules to strike the slanted lower surface, the amount of lift generated can be

FIGURE 2

Bernoulli's Principle

In the 1770s Daniel Bernoulli discovered this law of nature: The pressure of a fluid always decreases as its rate of flow increases.

To demonstrate, hold the narrow edge of a lightweight piece of writing paper (approximately 3 x 8 in or 7.5 x 20 cm) between thumb and forefinger, letting the free end droop. Then blow over your thumb and along the paper. If done correctly the drooping end should rise because the moving air exerts less pressure downward than the still air beneath does upward. Consequently the air beneath pushes the paper upward. A lifting force has been created.



increased. This slanting is called the *angle of attack*. If this angle is too steep the wing *stalls* and lift stops.

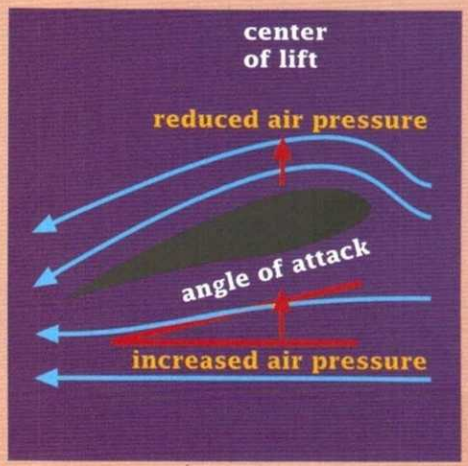
The point where all lift appears to be concentrated on a wing is called its *centre of lift* and is located at the point of maximum wing thickness about one third of the way between the leading and trailing edges.

FIGURE 3

How a wing creates lift

1. A wing increases the speed of the airflow over its upper surface so that pressure in this area is reduced. This is accomplished by making the upper wing surface curved — called camber. The distance from front to back along the curved upper surface is greater than along the lower one. Because the molecules flowing along the curve have farther to travel than the ones beneath, they increase their speed and become spaced farther apart in order to resume their former position when they leave the wing at the trailing edge. This faster moving air exerts less pressure, which means that a partial vacuum is created above the wing — suction. (By the application of Bernoulli's Principle.) The now higher pressure beneath pushes the wing upward into the vacuum, creating a lifting force. This lift acts through a point about one third of the distance between the leading and trailing edges of a wing, the point of maximum camber.

2. The lifting force can be increased if the leading edge of the wing is raised slightly. This incline is called the angle of attack. It allows the airflow to strike the lower surface. As air is deflected downward, it provides a force in the opposite direction. This additional pressure beneath the wings increases the overall lifting force. If the angle is more than about 15 degrees lift stops. The wing has stalled. Aircraft that are designed to fly at very high speeds have thin wings with only slight camber. Every wing design of any particular cross-section shape has a best angle of attack.



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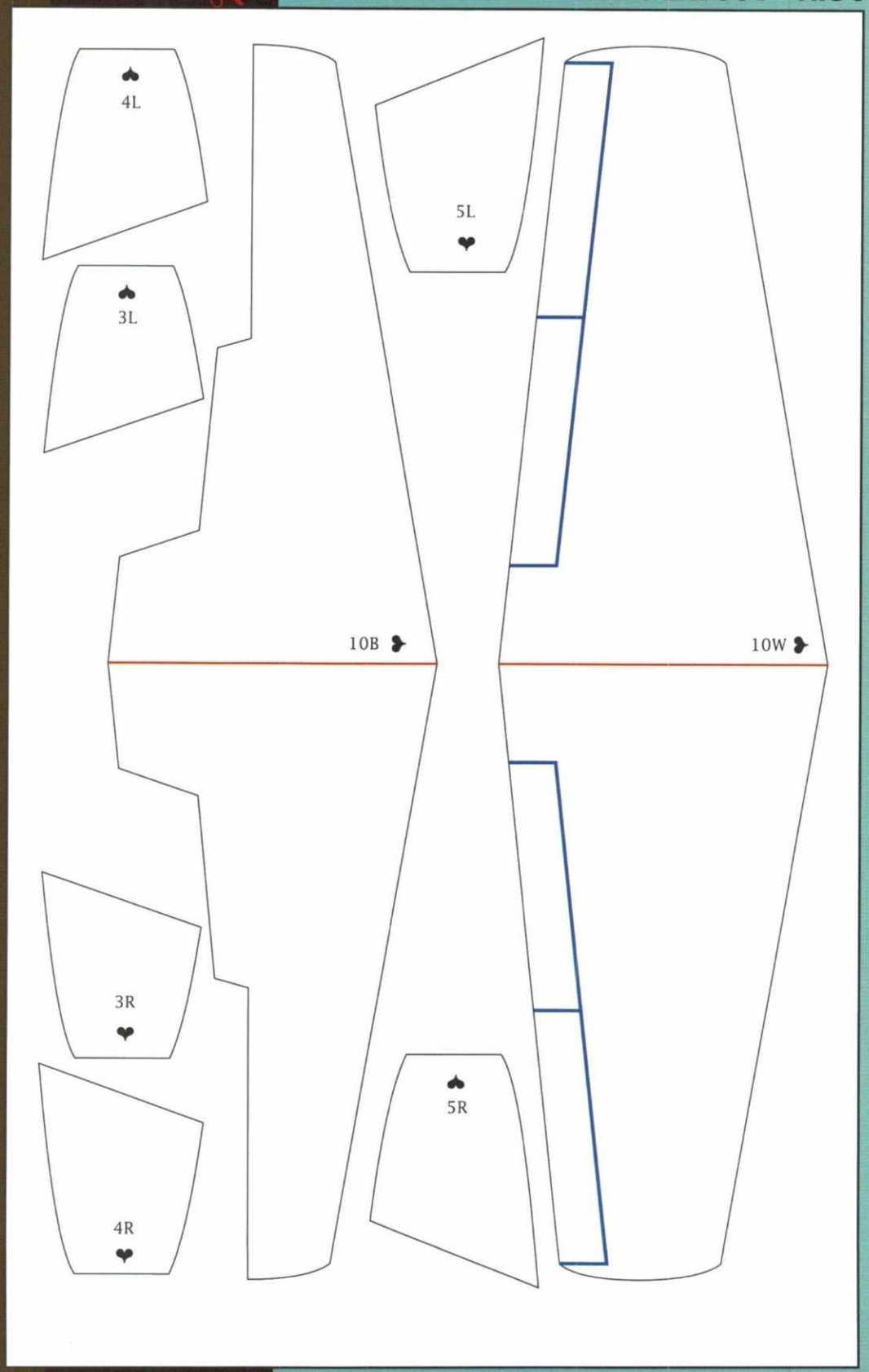
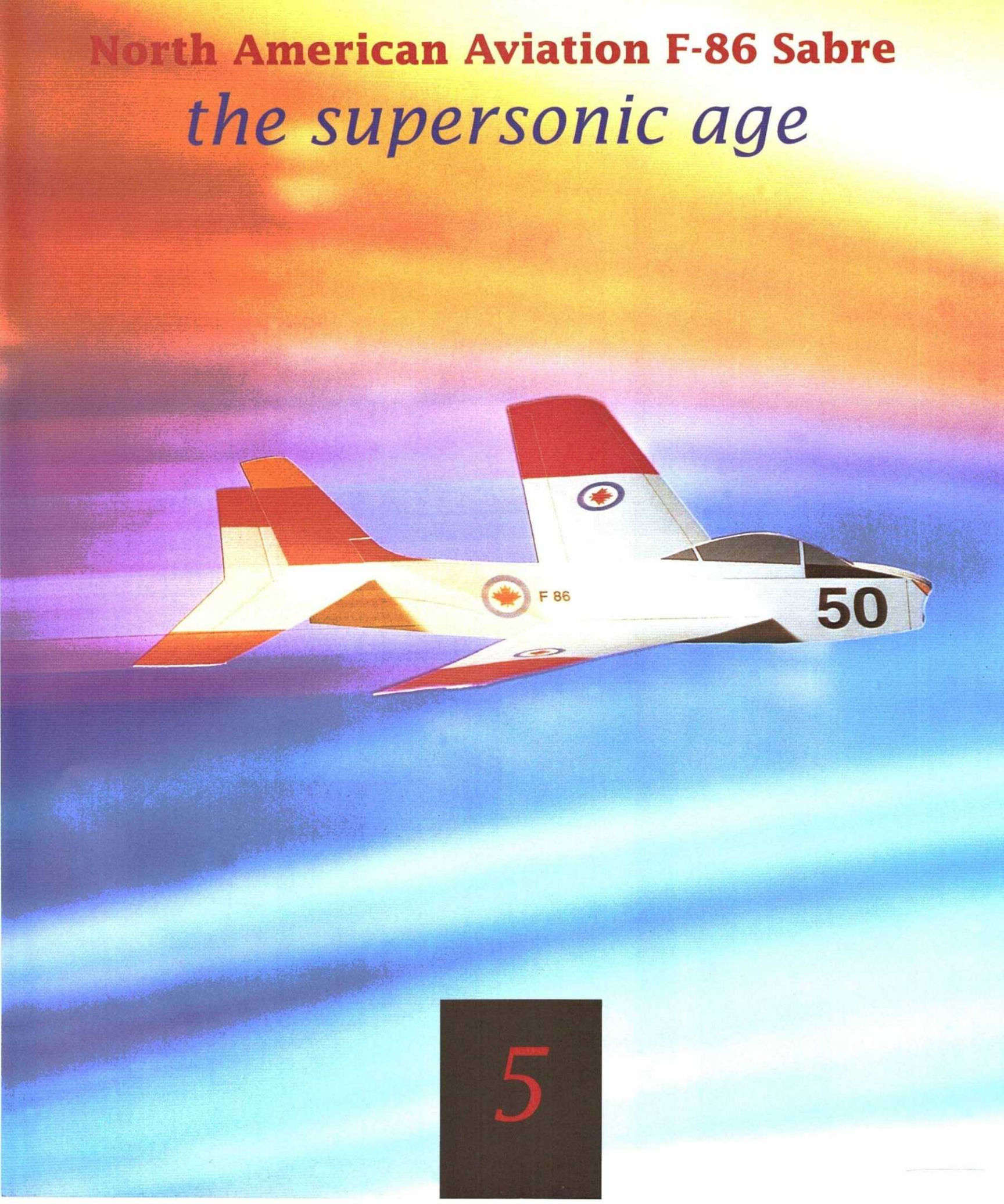
PARTS LAYOUT – MiG-9



North American Aviation F-86 Sabre

the supersonic age



5

Building the Sabre

1

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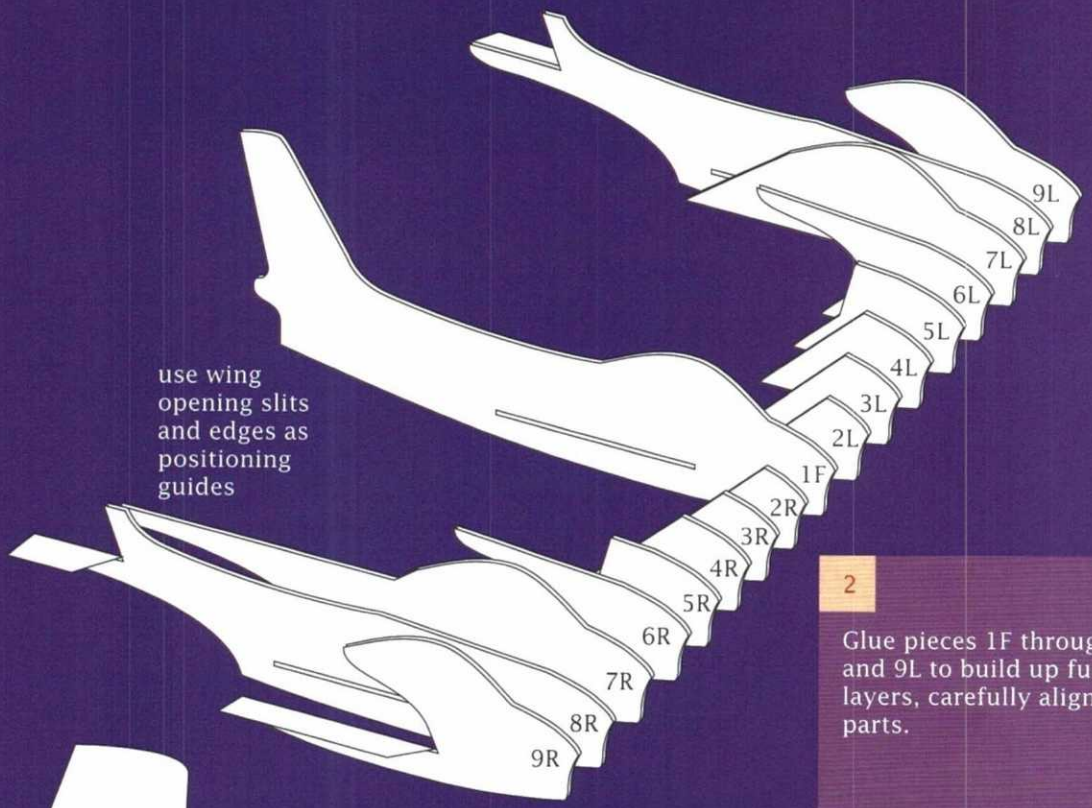

use wing opening slits and edges as positioning guides

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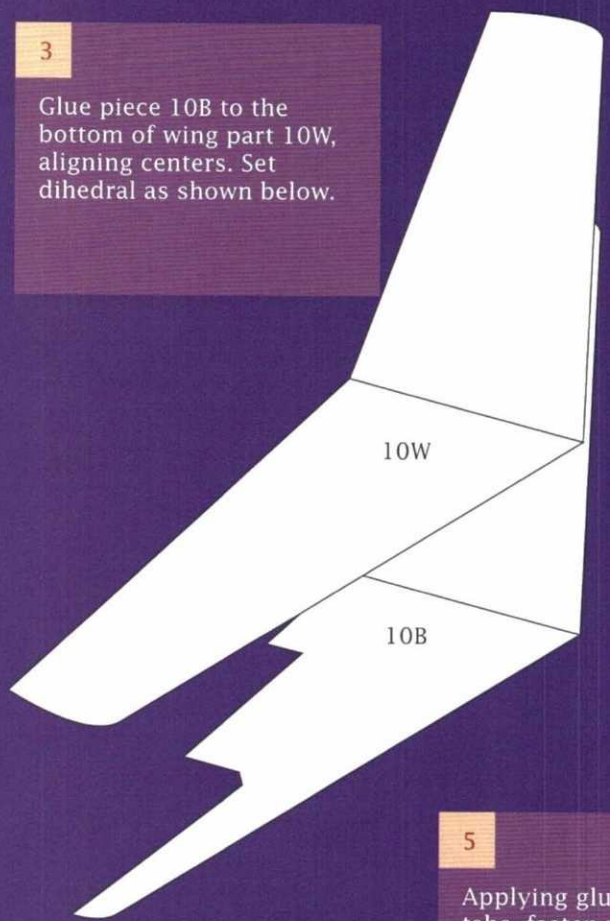

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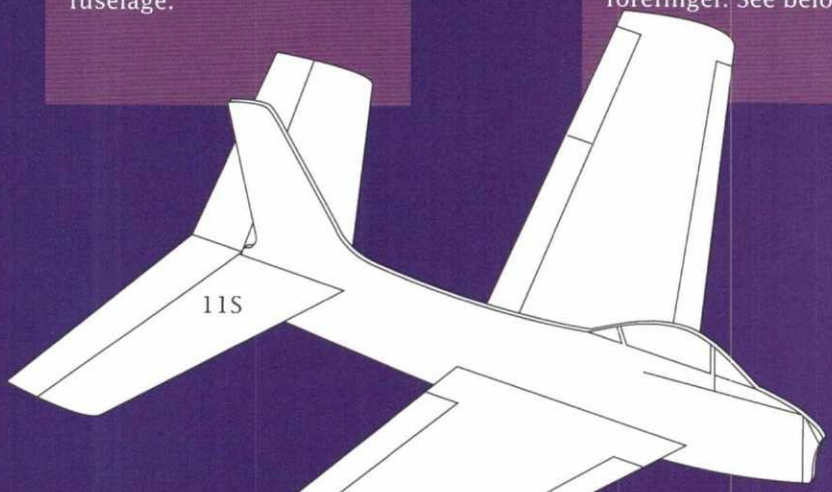

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Camber the wings by curving the paper gently between thumb and forefinger. See below.

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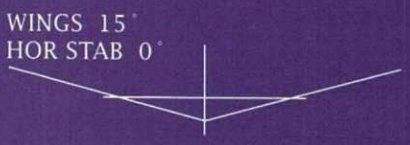

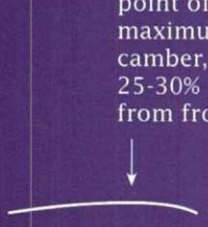

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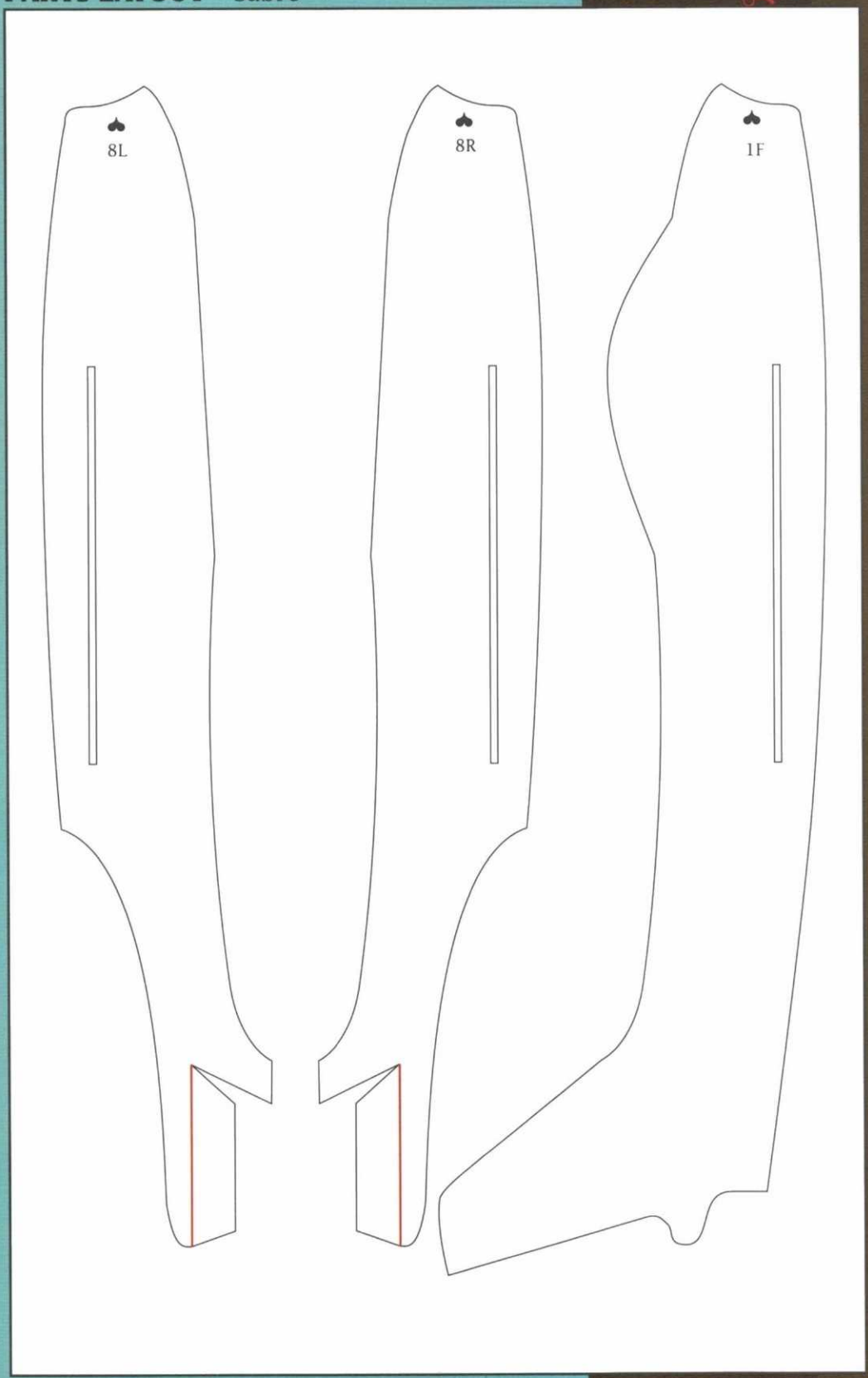
PARTS LAYOUT – Sabre



As an aircraft is propelled forward to create lift, air molecules are pushed aside causing a certain amount of resistance. On the one hand this resistance turns into the pressure that makes lift possible; on the other hand, it becomes *drag*, which slows a plane down. The resistance of air molecules being disturbed by forward motion is called *pressure drag*. Furthermore, any surfaces on an airplane

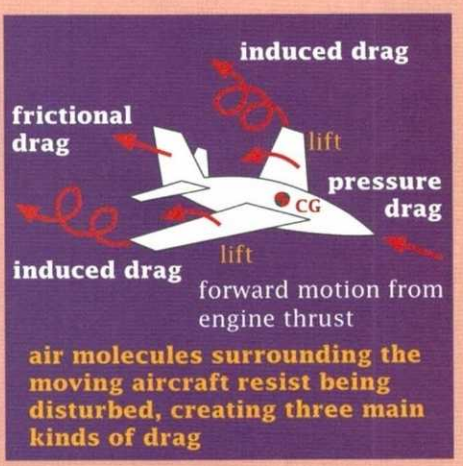
FIGURE 4

Drag — the resisting force of air
Thrust — a propelling force

The thrust from the engine propels a plane through the air, but air resists being disturbed. This is called drag. It slows a plane down and its force increases with speed. Drag and thrust counteract each other.

At subsonic speed there are three kinds of drag: pressure drag, induced drag, and frictional drag. These combine to make up the overall drag acting on an aircraft in flight. Pressure drag is the general resistance of air to disturbance. This is what you feel when you wave your arm or run. The bigger the frontal area of an object, the greater this drag. Air always flows from an area of high pressure to an area of low pressure; therefore, in the process of generating lift, air slips around the wingtips creating a vortex. This is induced drag. Because of the relative stickiness of air, any surface of the aircraft over which air flows creates frictional drag.

For the efficient operation of aircraft, reducing drag has been a major objective in airplane design. It is called streamlining.



air molecules surrounding the moving aircraft resist being disturbed, creating three main kinds of drag

not parallel to the airflow add to this drag, including a wing's angle of attack and stabilizers adjusted to maintain straight and level flight.

Additionally, the pressure differential above and beneath a wing creates a vortex as air slips around the wingtip from the area of high pressure to that of low pressure. This turbulence, which always accompanies lift production, is called *induced drag*. This drag varies depending on the shape and efficiency of the wing.

Air molecules flowing over an object also tend to stick to the object's surface, adding to the air's resistance, called *frictional drag*. The smoother the surface, the less this drag is.

EFFECTS OF HIGH SPEED

The various forces combine into a general force of drag, which increases with speed. At very high speed, however, the nature of this force changes, becoming a force called *compressibility drag*. The air molecules simply cannot move aside fast enough and they begin to pile up. The air surrounding the plane begins to resemble the wake of a powerboat in water. Quite suddenly, at a certain speed, this increases the overall drag sharply. Buffeting is encountered. An airplane that was stable at a slower speed now loses its stability.

Additionally, frictional drag begins to generate heat, and the faster the speed the higher the

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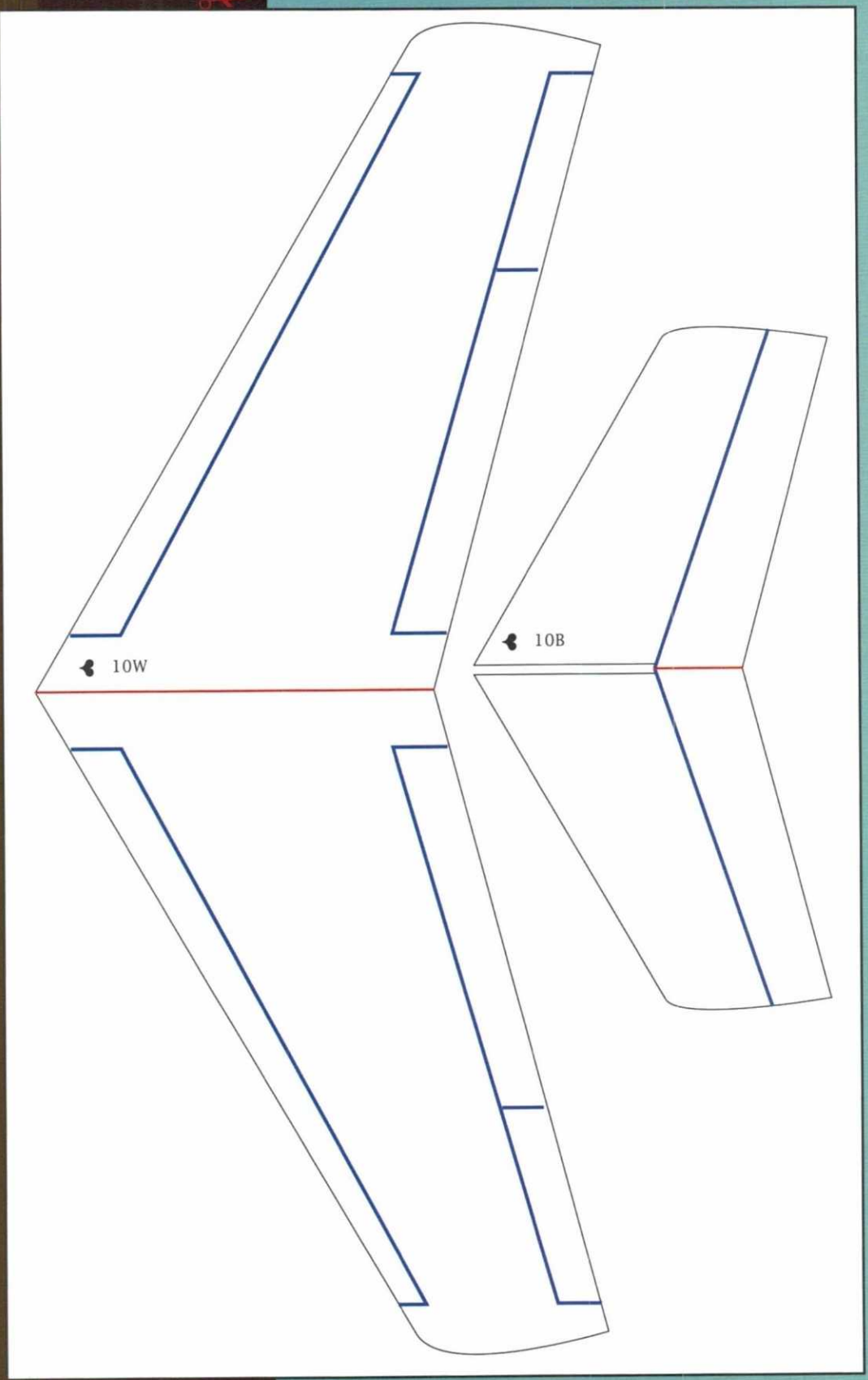
PARTS LAYOUT – Sabre



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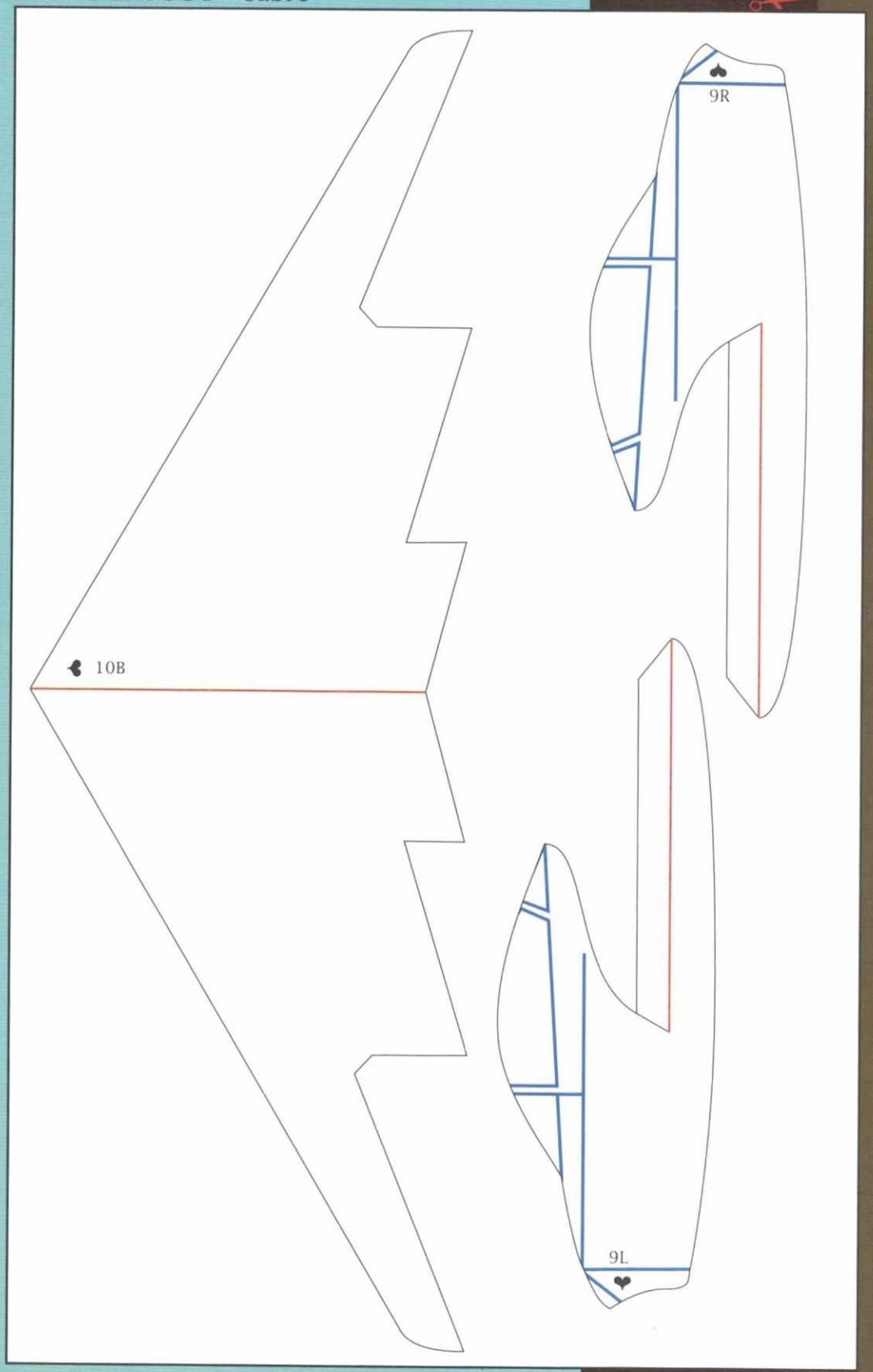
PARTS LAYOUT – Sabre



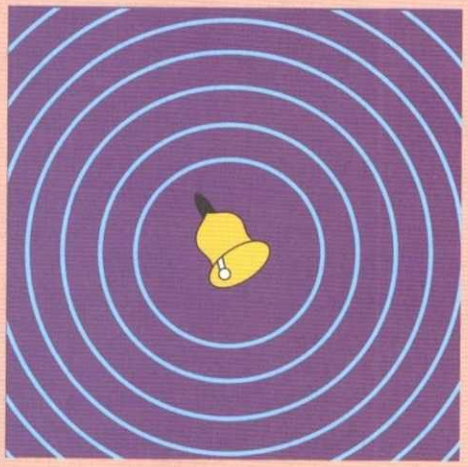
temperature becomes. For example, an airplane flying three times the speed of sound at 10,000 feet would heat up to 900 degrees F. Every material has a temperature above which it weakens and loses its usefulness. So the speed and altitude at which an airplane can travel are limited by the amount of heat its airframe can withstand, known as its *thermal barrier.*

THE SPEED OF SOUND

Sound is transmitted by pressure waves in the air. The speed at which the waves move is the speed of sound, or *sonic speed.* The speed of sound varies with air density and temperature. At sea level it is about 760 miles per hour, but is less at high altitude. Sonic speed is sometimes referred to as the *sound*

FIGURE 5
Sound and air pressure

Sound is transmitted by pressure waves in the air. The speed at which these waves travel is called sonic speed. It varies with air density and pressure. When a sound is made, such as the ringing of a bell, the waves move away in all directions. To a person nearby these pressure waves striking the ears are interpreted as the sound.



barrier because the buffeting of compressibility drag made some people believe speed beyond it was impossible.

Austrian physicist, Ernst Mach, studied the action of solid objects moving through air at very high speed, and developed a method of measuring speed in terms of the speed of sound. His work was not understood for a long time, but became important as aircraft began to encounter compressibility drag as they approached the speed of sound. This speed came to be known as Mach 1, twice the speed of sound as Mach 2, and so on.

Overall shape and design determine the degree of stability inherent in an airplane. The stability problems of compressibility drag occur because an

FIGURE 6

Sound and motion

When a sound-producing object, such as an airplane, is in motion, the airplane's speed affects the spacing of its sound waves. The waves ahead of it are spaced closer together than the ones behind. The faster the airplane flies, the closer the spacing of the forward waves becomes until, at a certain speed, the airplane catches up with the waves and they can no longer move forward.

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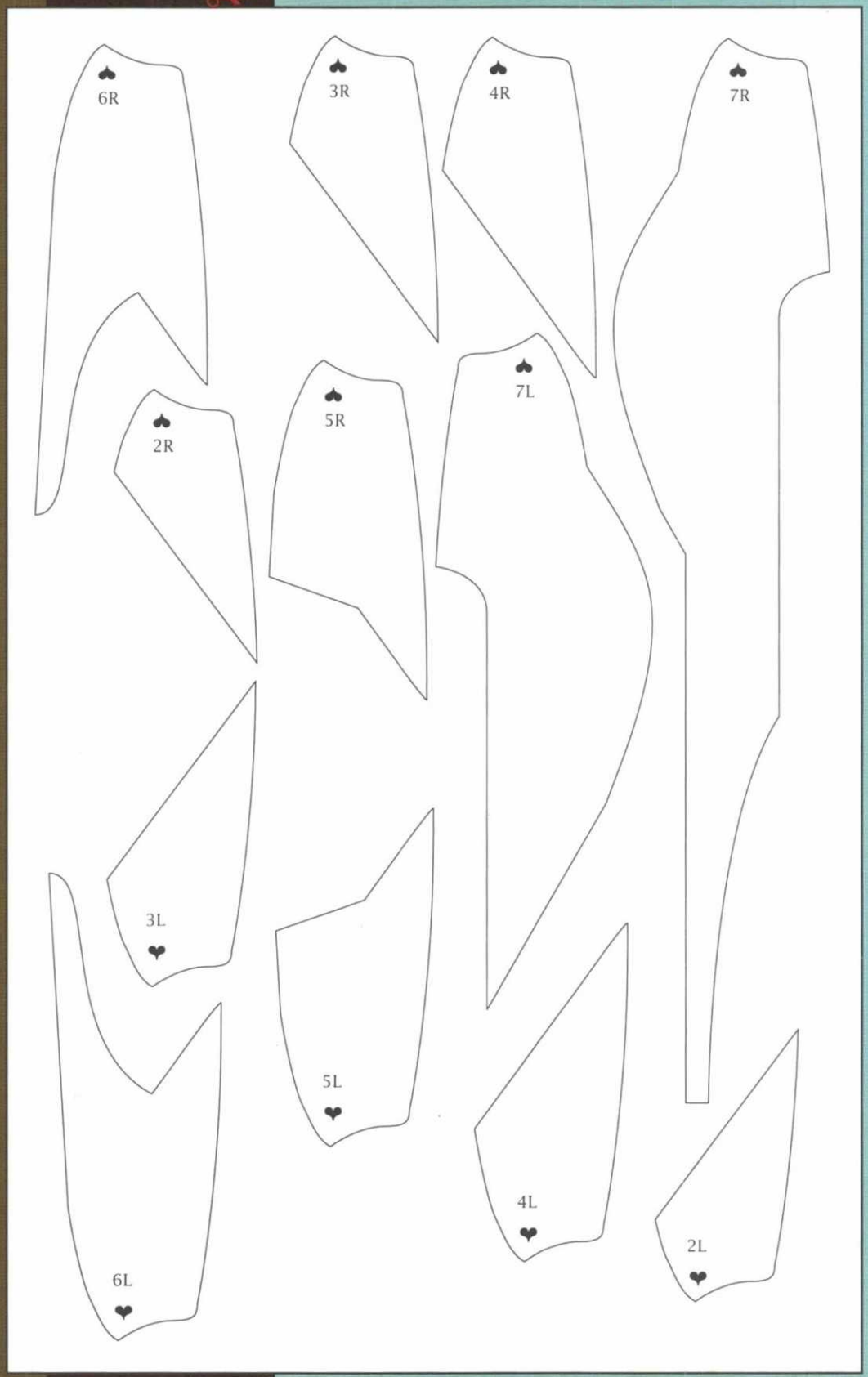
- Use the blue lines as guides for adding details to the plane.
- Indicates the front edge of the piece.

NOTE
CUT OUT PHOTOCOPY ONLY

PARTS LAYOUT – Sabre



de Havilland DH-106 Comet

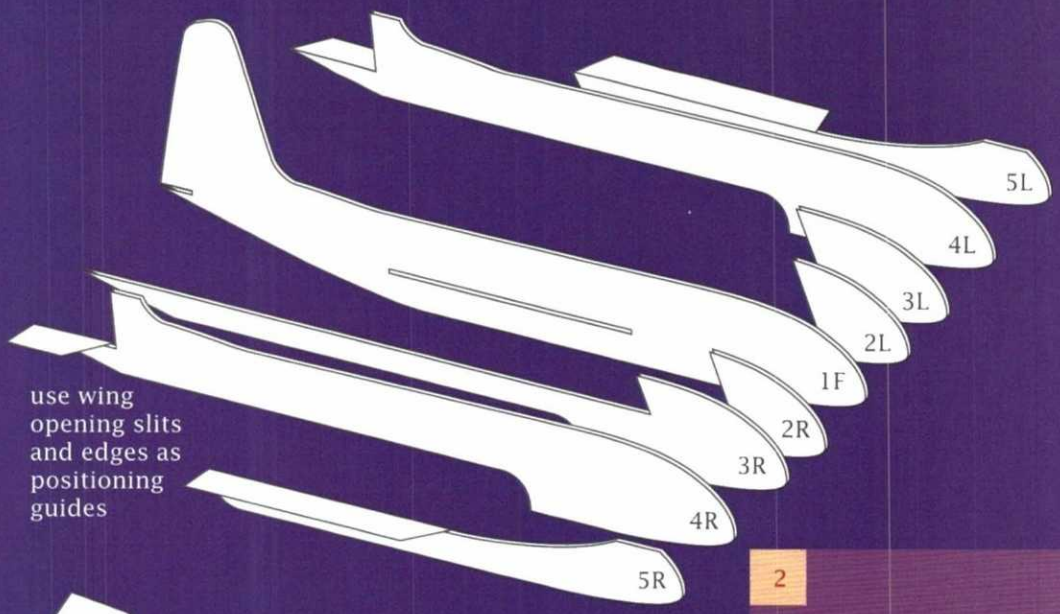
jet transportation begins

6

Building the Comet

1

Photocopy the parts layouts for this model. Then cut out and prepare the pieces. (See the general instructions beginning on p 4.)



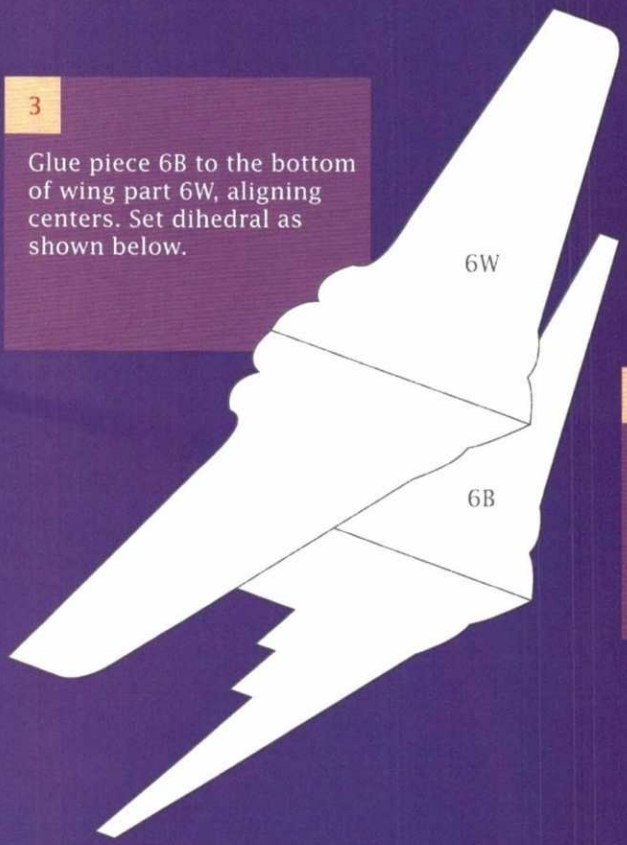
use wing opening slits and edges as positioning guides

2

Glue pieces 1F through 5R and 5L to build up fuselage layers, carefully aligning parts.

3

Glue piece 6B to the bottom of wing part 6W, aligning centers. Set dihedral as shown below.

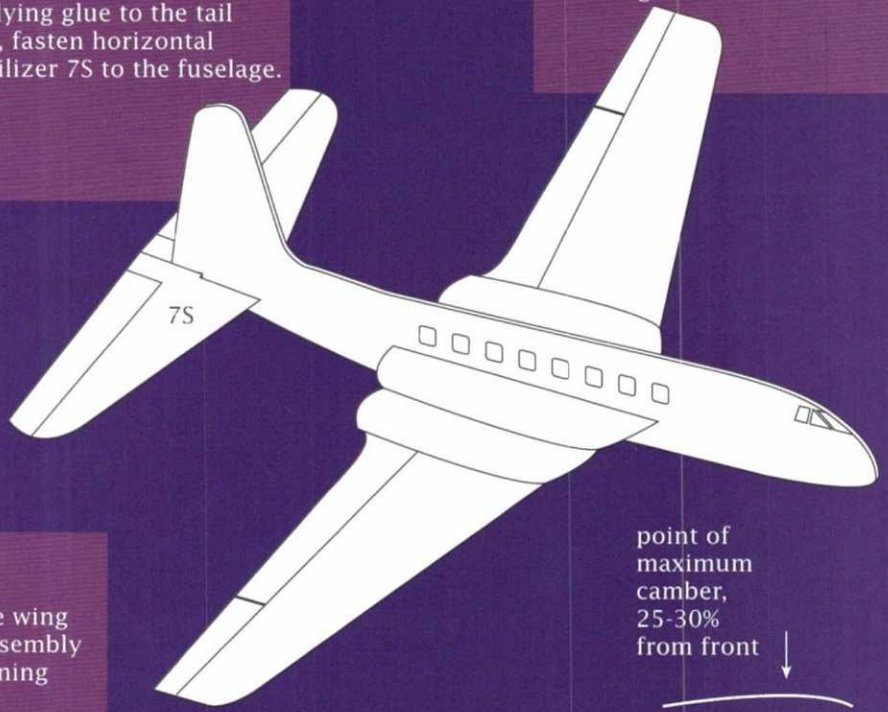


4

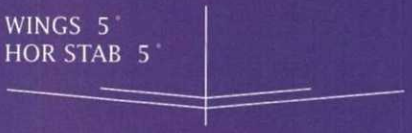
Applying glue to the tail tabs, fasten horizontal stabilizer 7S to the fuselage.

6

Camber the wings by curving the paper gently between thumb and forefinger. See below.



WINGS 5°
HOR STAB 5°



5

Applying glue to the wing tabs, fasten wing assembly to the fuselage, aligning center lines.

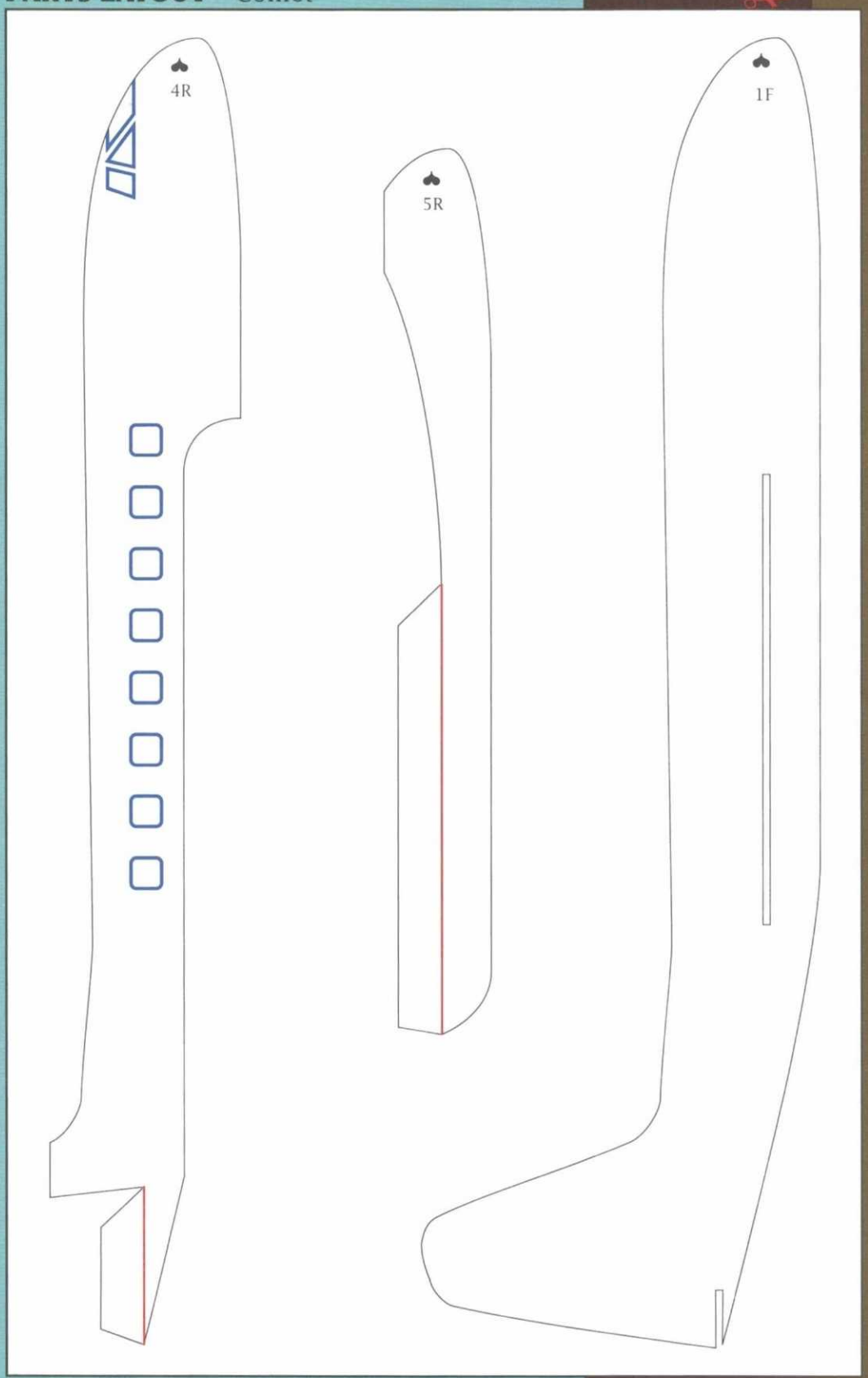
point of maximum camber, 25-30% from front

CORRECT CAMBER

NOTE
- Cut on lines shown in black.
- Score lines in red.
- Use the blue lines as guides for adding details to the plane.
- ♠ Indicates the front edge of the piece.

NOTE
CUT OUT PHOTOCOPY ONLY

PARTS LAYOUT – Comet



airplane catches up with its own sound waves flowing outward away from the craft. These pressure waves interfere with lift and stability.

FIGURE 7

Three-axis control in a standard aircraft

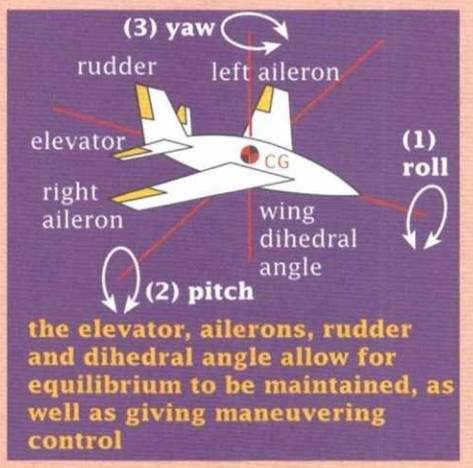
An aircraft in flight can rotate about its center of gravity along three axes. (1) Its rolling motion is controlled by ailerons in the wings. (2) Pitch is controlled by an elevator in the horizontal stabilizer. (3) Yaw is controlled by a rudder in the vertical stabilizer. These are small flaps on the trailing edges that swing back and forth like a door on its hinges. When operated in harmony, these controls provide equilibrium in flight — three-axis control.

The ailerons move differentially. When one is moved up the other goes down, and vice versa, creating a difference in lift between the two wings — down, lift is increased; up, lift is decreased. This makes the aircraft roll into a banking turn to left or right.

By moving up or down, the elevator controls the air flowing over the horizontal stabilizer. When it is raised the pressure over the upper surface of the stabilizer increases, pushing downward, which pitches the nose up as the plane rotates about the center of gravity.

The rudder swings to left or right and keeps the aircraft pointing straight into the airflow during flight.

Roll stability is improved if the wings angle upward away from the fuselage in a dihedral angle. In level flight each wing produces the same amount of lift. When an aircraft with dihedral is banked, the downgoing wing's exposed surface lengthens and its lift consequently increases, while the upgoing wing's exposed area shortens and its lift decreases. This lift differential causes an opposite rolling force and the plane rights itself, restoring equilibrium. The greater the dihedral angle the more stable the airplane.



the elevator, ailerons, rudder and dihedral angle allow for equilibrium to be maintained, as well as giving maneuvering control

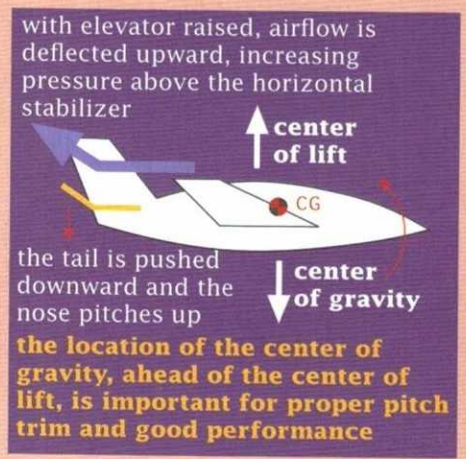
All aircraft in flight tend to be unstable in three ways: they *roll* left or right along a longitudinal axis, *pitch* nose up or down along a lateral axis running through the wings, and *yaw* from side to side around a vertical axis. To be controllable, the axes must intersect at the center of lift. The center of lift, in turn, must lie just behind the center of gravity, the balancing point where all the weight appears to be concentrated. This results in a well balanced controllable airplane.

An airplane pivots freely about this balancing point. This movement is stabilized for steady flight by some combination of *vertical* and *horizontal stabilizers*, and sometimes by wing slant, upward slightly away from the fuselage in a *dihedral*

FIGURE 8

Angle of attack and speed

Every wing is most efficient within a certain range of angle of attack and speed. With the center of gravity ahead of the center of lift, a certain amount of positive trim is always necessary to maintain a proper flight attitude. At slow speed positive trim also helps in maintaining balance despite any air turbulence. As speed is increased by adding power, the angle of attack must be decreased by the pilot to maintain level flight. The plane is retrimmed for the higher speed.


with elevator raised, airflow is deflected upward, increasing pressure above the horizontal stabilizer
center of lift
CG
the tail is pushed downward and the nose pitches up
center of gravity

the location of the center of gravity, ahead of the center of lift, is important for proper pitch trim and good performance

NOTE
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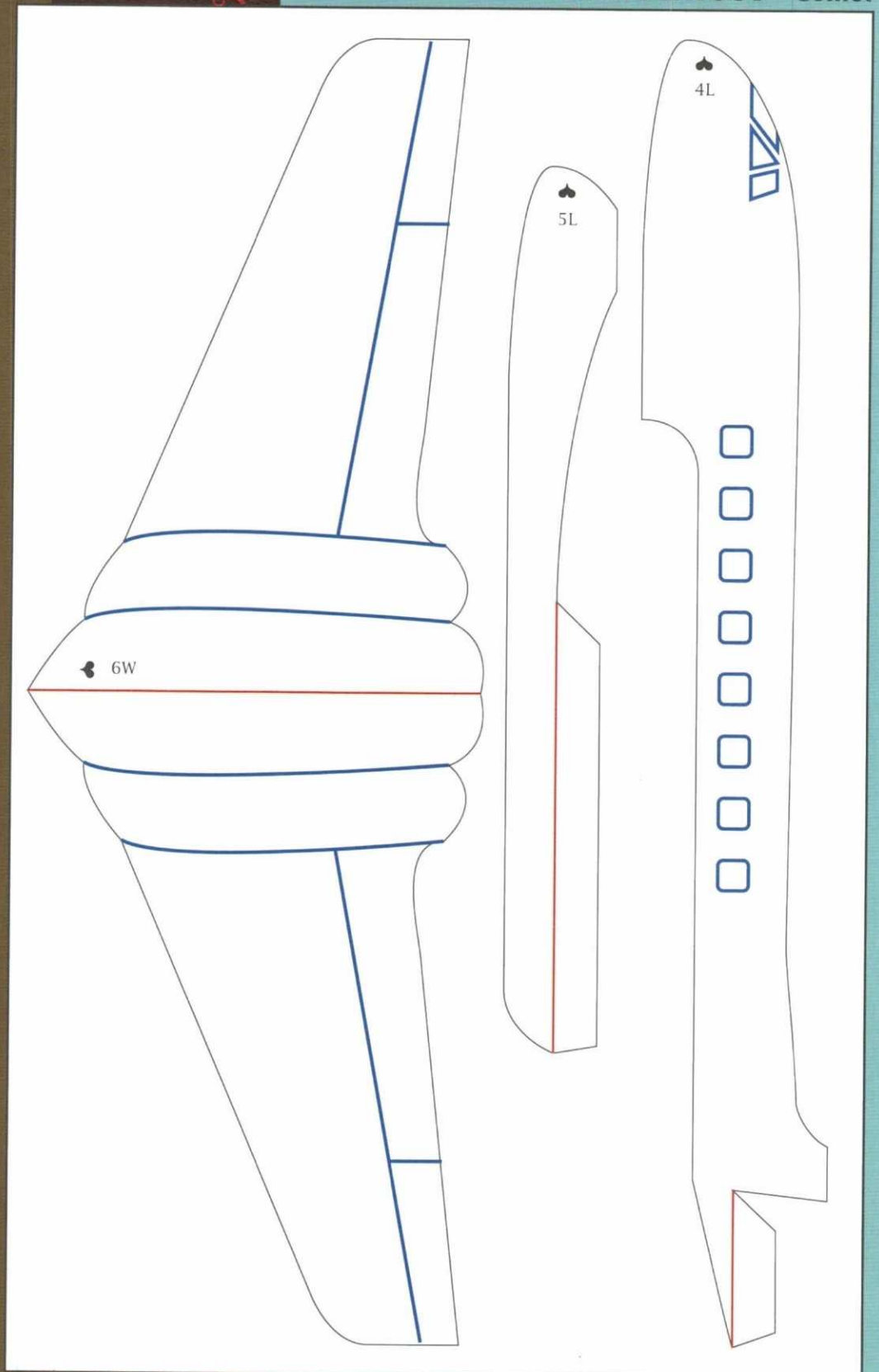
- Indicates the front edge of the piece.

NOTE
CUT OUT PHOTOCOPY ONLY

PARTS LAYOUT – Comet



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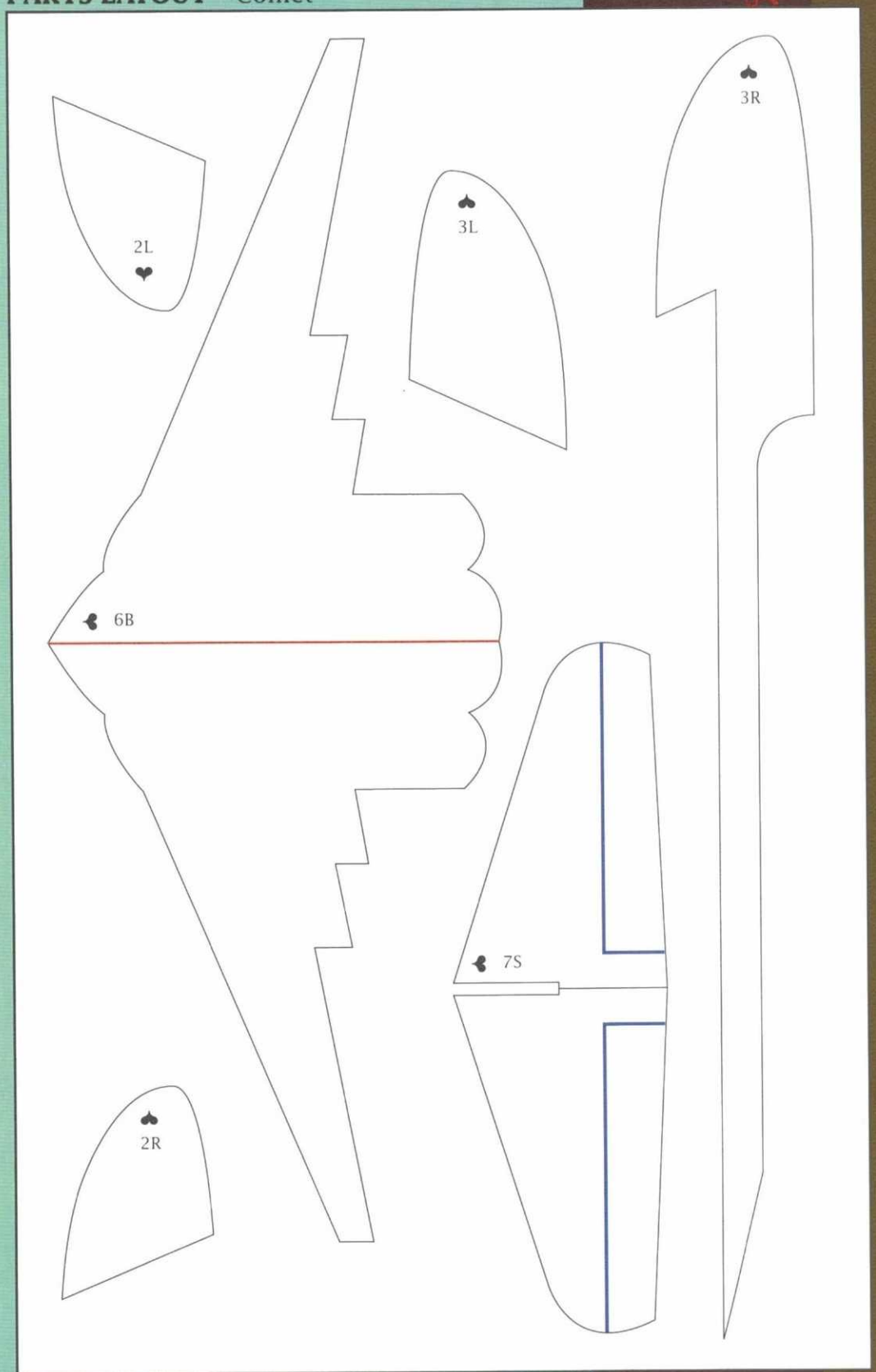
PARTS LAYOUT – Comet



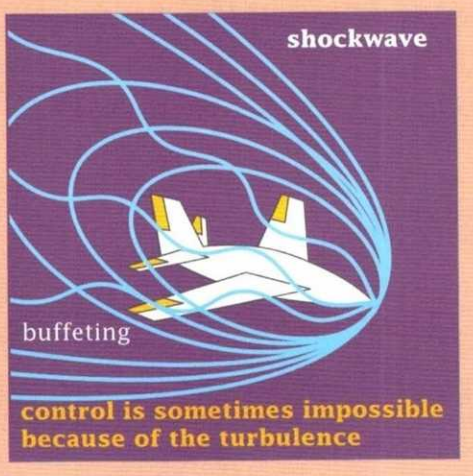
angle. Additionally, the horizontal and vertical stabilizers have small moveable surfaces *(control surfaces)* that are linked by cables and rods to stick and rudder pedals in the cockpit. By maneuvering them the pilot can make immediate adjustments and maintain equilibrium in changing conditions. The control surfaces also provide directional control for maneuvering the aircraft.

A well balanced plane can be adjusted *(trimmed)* to fly straight and level at any particular speed that the combination of airframe and propulsion system allow, requiring little pilot input. A particular angle of attack is maintained and the plane is dynamically stable.

FIGURE 9

Transonic speed and the shockwave

In their operation, wings and control surfaces produce pressure differentials. Sound waves are also pressure differentials. They move at a particular speed away from the source of the sound. As an airplane approaches sonic speed, it catches up with its own sound waves, which then no longer flow ahead of the plane (compressibility drag). A shockwave forms. This uneven airflow creates turbulence which interferes with the normal pressure differentials surrounding the airplane.



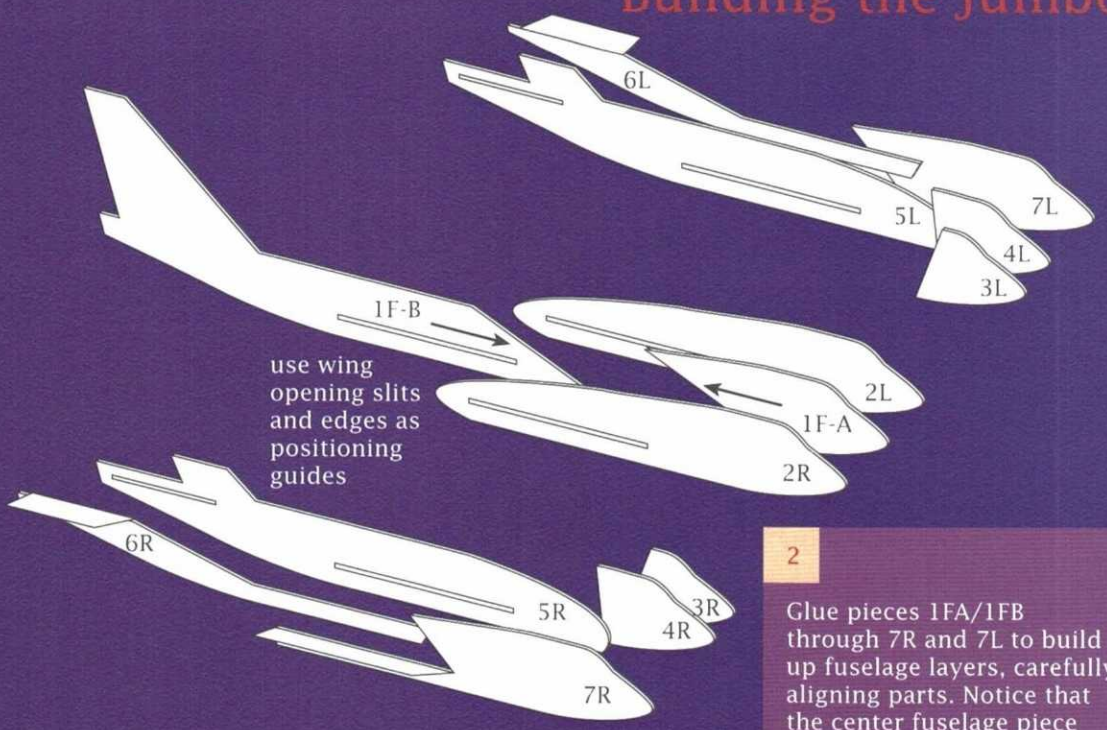
Boeing 747

jumbo transportation

Building the Jumbo

1

Photocopy the parts layouts for this model. Then cut out and prepare the pieces. (See the general instructions beginning on p 4.)

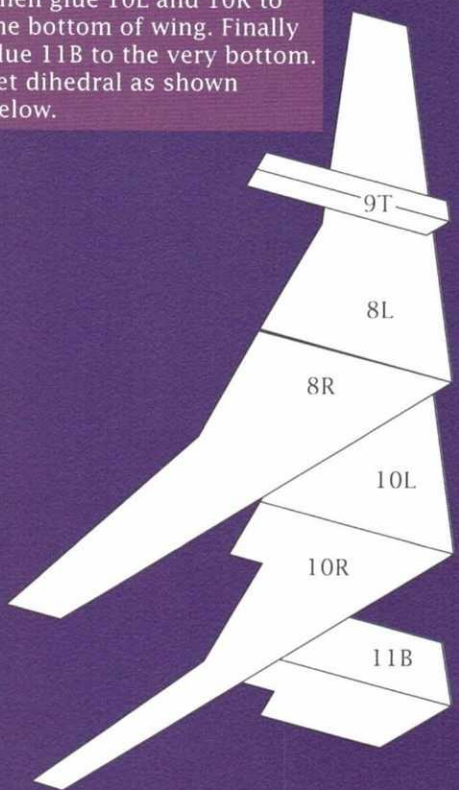


2

Glue pieces 1FA/1FB through 7R and 7L to build up fuselage layers, carefully aligning parts. Notice that the center fuselage piece consists of parts A & B.

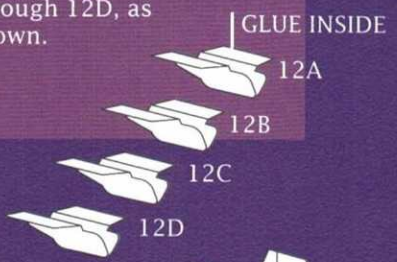
3

Bring wing parts 8L and 8R together, fastening with 9T. Then glue 10L and 10R to the bottom of wing. Finally glue 11B to the very bottom. Set dihedral as shown below.



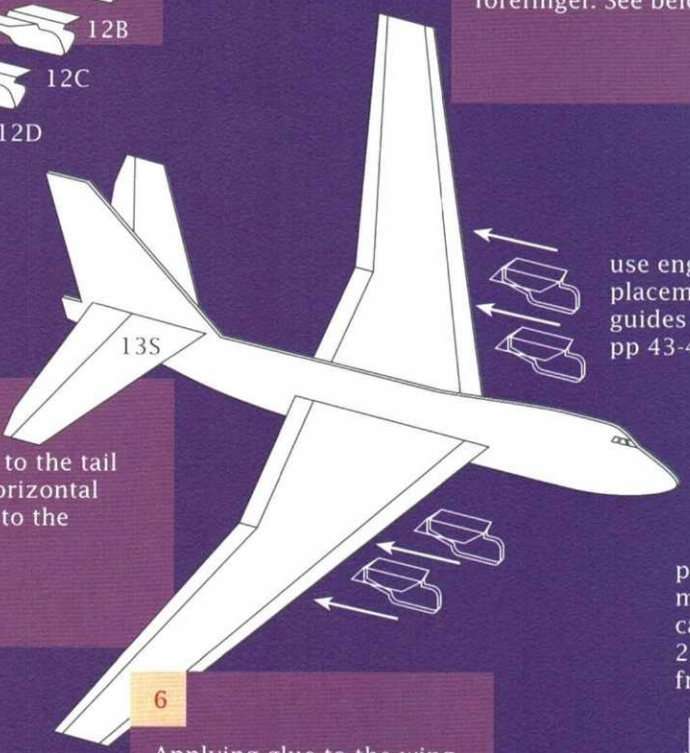
4

Glue the four engine pieces 12A through 12D, as shown.



5

Applying glue to the tail tabs, fasten horizontal stabilizer 13S to the fuselage.

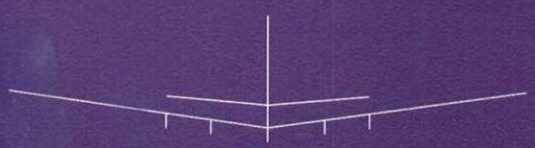


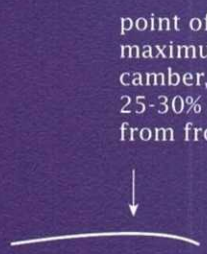
6

Applying glue to the wing tabs, fasten wing assembly to the fuselage, aligning center lines. Then glue two engines to the bottom of each wing.

7

Camber the wings by curving the paper gently between thumb and forefinger. See below.





When an airplane flies at subsonic speed air molecules slip around the airframe smoothly and sound waves move away ahead of the airplane uneventfully. If the airplane approaches the speed of sound, called *transonic* speed, no sound waves move away ahead of it. Instead air molecules build up into a *shockwave* at the leading edges of the airplane. Because air flows at different speeds around an airplane, with different kinds of drag and various pressures, at transonic speed the turbulence surrounding the airframe is tremendous. Stabilizers and control surfaces cannot compensate for it, and the plane rolls, pitches, and yaws unpredictably.

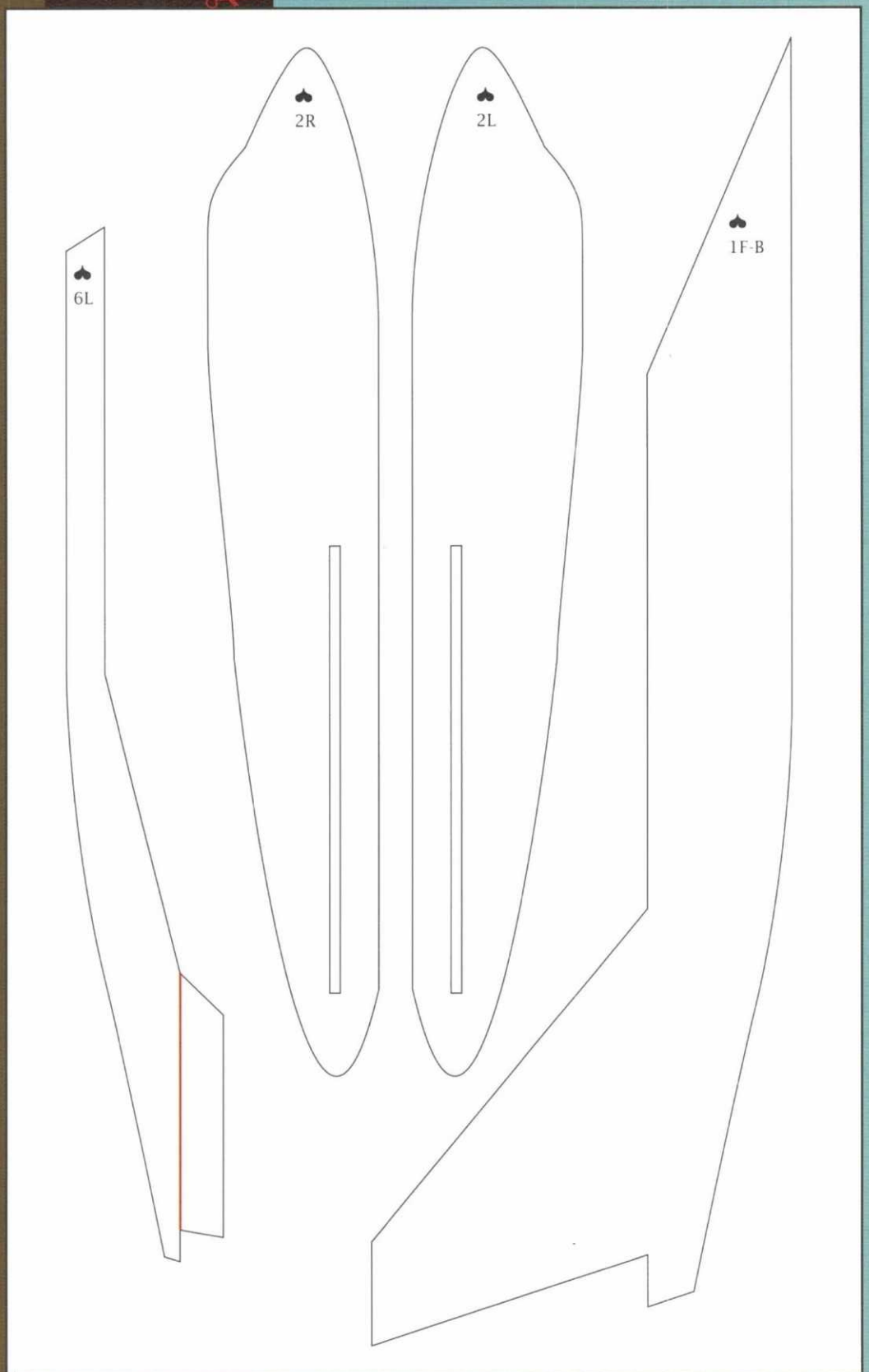
When an airplane exeeds the speed of sound, or goes *supersonic*, the shockwave moves farther and farther back as the Mach number increases. Besides upsetting the airplane, the shockwave is heard as a loud explosion to an observer on the ground. This is the *sonic boom*, which has enough force to break windows.

Engineers knew about the kinds of difficulties experienced by pilots flying at transonic speed, and they knew that the answer to controllable supersonic flight lay in the airplane's shape. It had to be shaped and streamlined in such a way that the shockwave and its turbulent airflow were directed away from all of a plane's control surfaces. There was some guesswork involved in this, since no testing

NOTE
- Cut on lines shown in black.
- Score lines in red.
- Use the blue lines as guides for adding details to the plane.
- ➧ Indicates the front edge of the piece.

NOTE
CUT OUT PHOTOCOPY ONLY

PARTS LAYOUT – 747



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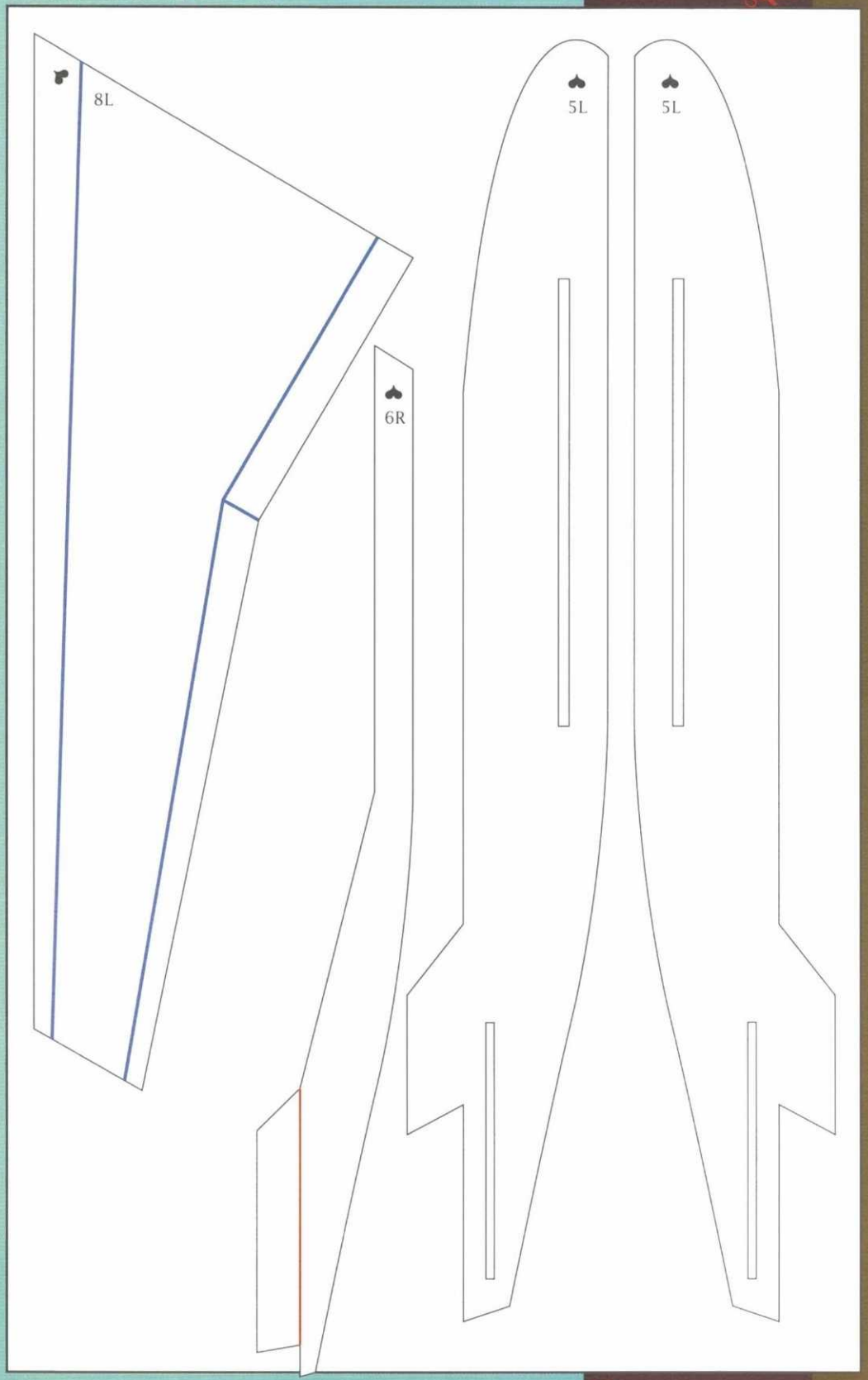
PARTS LAYOUT – 747



could be done beforehand. It was discovered quite by accident how to approach this problem practically.

SHAPE FOR SUPERSONIC FLIGHT

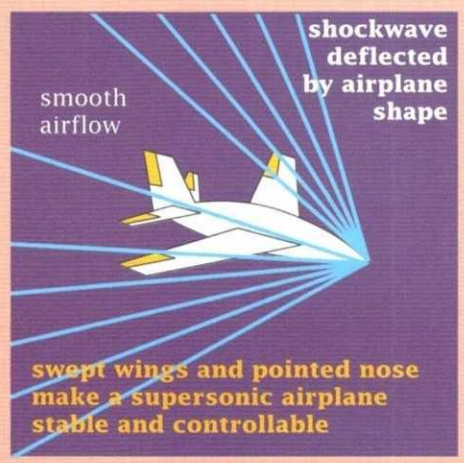
A wing having a low *aspect ratio* (one that is short and broad) and being very thin, was known to delay the problems of compressibility drag. The difficulty was that no one knew what particular shape to make such a wing so that at the same time it still produced lift efficiently.

After the war engineers doing research examined the He 176 and Me 262. The 262 was a twin engine design. When it was being fitted with jet en-

FIGURE 10

Supersonic speed

When an airplane flies faster than the speed of sound, airflow is once more smooth but it now has a different flow pattern. The shockwave is wedge-shaped and attached to the airplane's surfaces. It is deflected by the airplane's shape. The faster the airplane travels, the farther back the shockwave moves. For stability at high speed, the shockwave must be directed away from the plane's control surfaces at every speed. Different pressures in the shockwave are used to create lift.


shockwave deflected by airplane shape
smooth airflow
swept wings and pointed nose make a supersonic airplane stable and controllable

gines, one underneath each wing, the plane's center of gravity was too far forward. In order to balance the plane the engines were moved farther back by sweeping the wings back. This swept-back design also coincidentally solved both the shape and lift problems.

Sweeping a wing back makes the wing appear to have a lower aspect ratio than it actually has. This fools the air, which now flows a longer distance diagonally across the backward-slanting surface.

Britain, leading the way in jet development after the war, built the de Havilland DH 108 Swallow, a swept wing experimental plane designed solely to go supersonic. However, in one attempt, in 1946, it unfortunately pitched wildly as it encountered compressibility drag, and broke up.

FIGURE 11

Wing sweepback

By sweeping a wing back, the air flowing across it has to travel farther than if the wing were straight. This has the effect of reducing the buffeting of compressibility drag at transonic speed.

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NOTE
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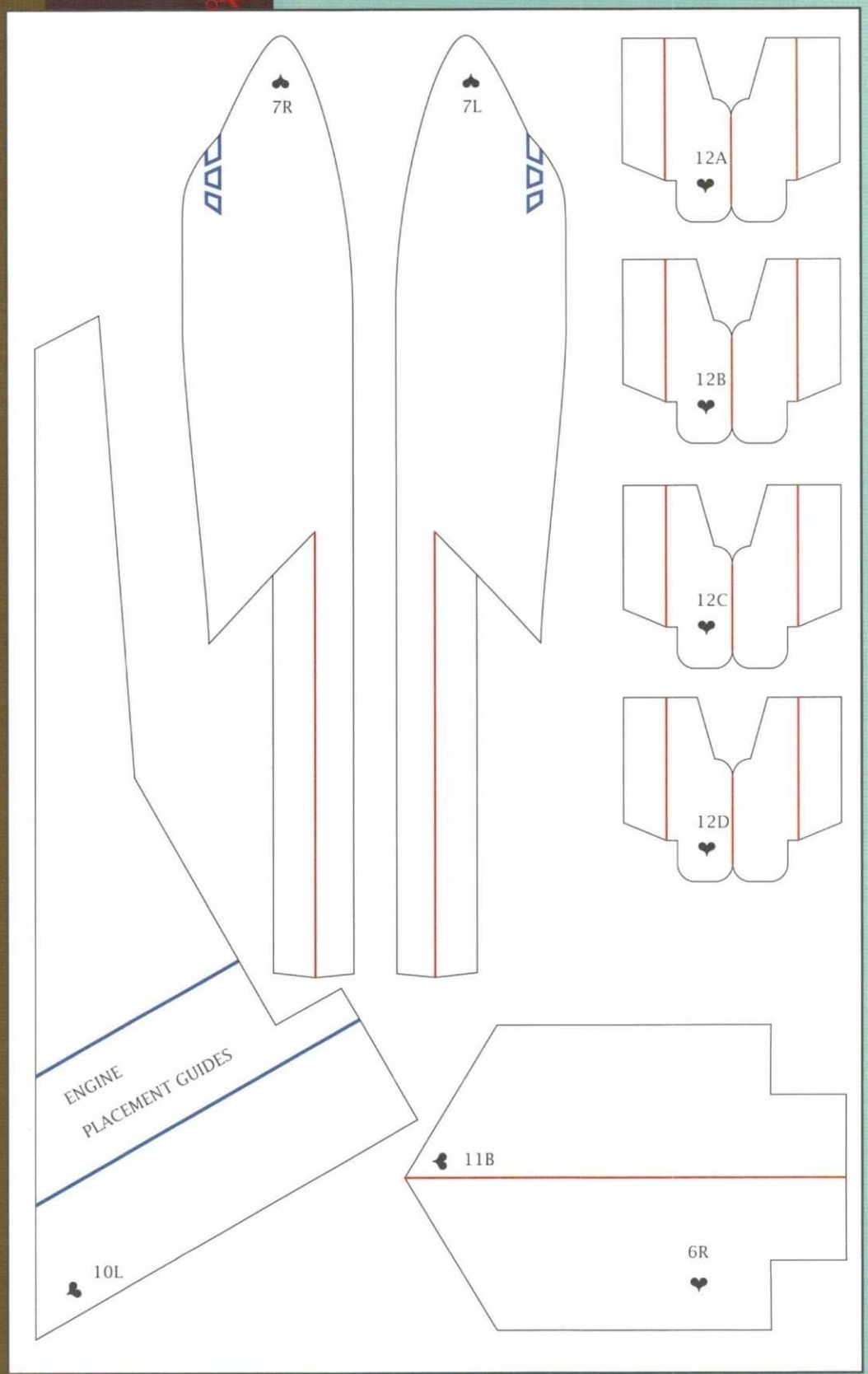
PARTS LAYOUT – 747



NOTE
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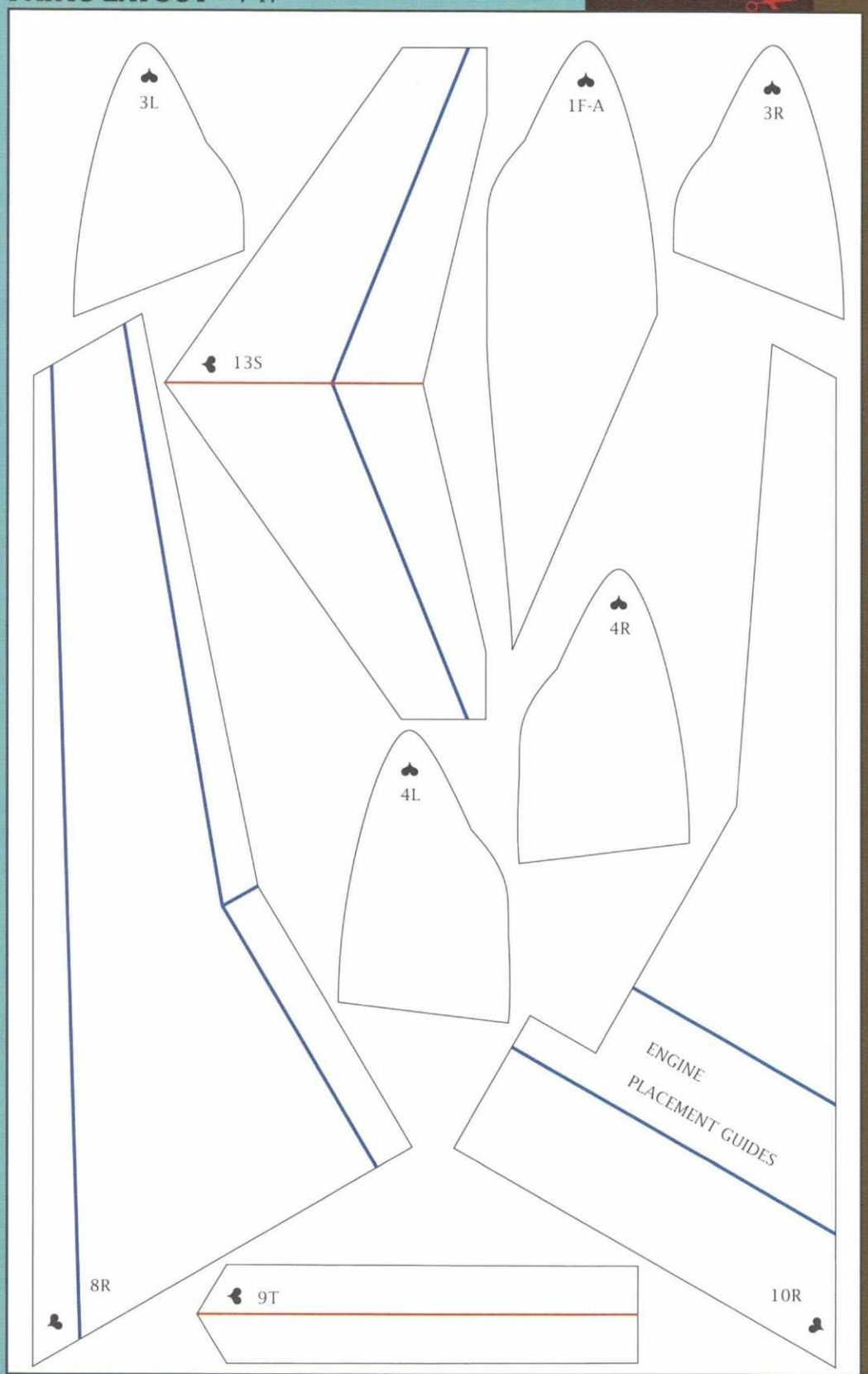
NOTE
CUT OUT PHOTOCOPY ONLY

PARTS LAYOUT – 747



Sweepback alone was not the answer. New and unforeseen handling problems occurred. After the Swallow's loss of control engineers were cautious in the use of swept wings until the new problems were solved.

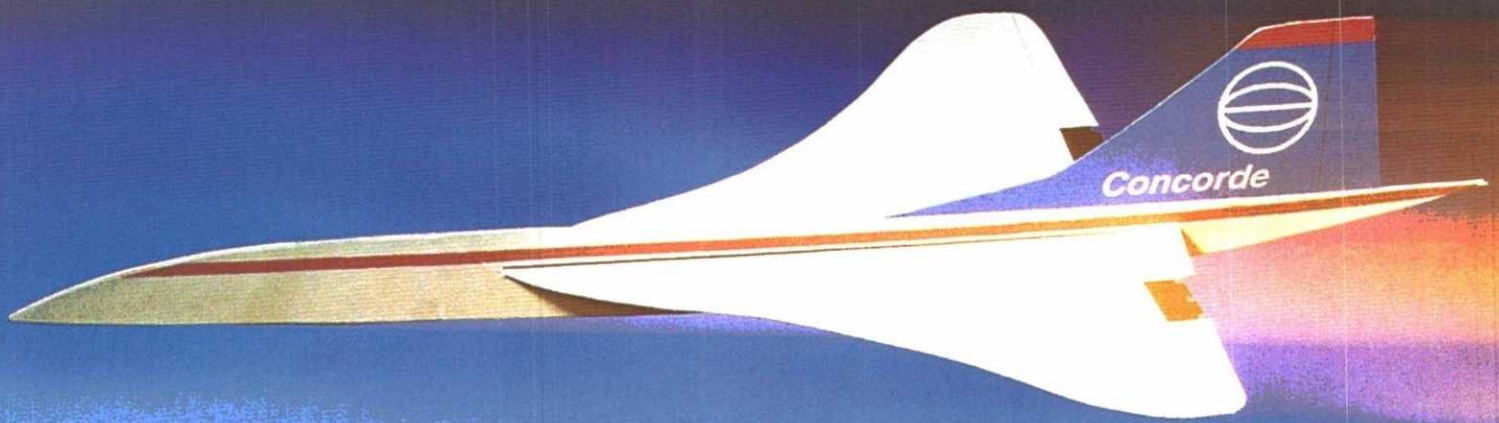
Thereafter British designers continued to use the Gloster Meteor as a test plane for developing jet propulsion and high speed flight, pushing it ever closer to the speed of sound. They had another high speed plane under development, the de Havilland Vampire. In 1946 the Meteor held the world speed record at 613 miles per hour and the Vampire held the world altitude record at 60,000 feet. But the limits of these planes had been reached. Mach 1 remained unattained.

The British shared their knowledge with American and Russian designers during the war, and in 1942 the first American jet, the Bell Aircraft P-59 Aeracomet was powered by a British engine. This plane proved not suited to high speed and its performance was modest.

In the employ of Lockheed was a young engineer by the name of Kelly Johnson. Under his leadership, at a lab known as the Skunkworks, improvements in both airframe and jet propulsion appeared in the Lockheed P-80 Shooting Star. **(#3, p 18.)** In 1947 this jet surpassed the speed of the

Concorde SST

supersonic transportation

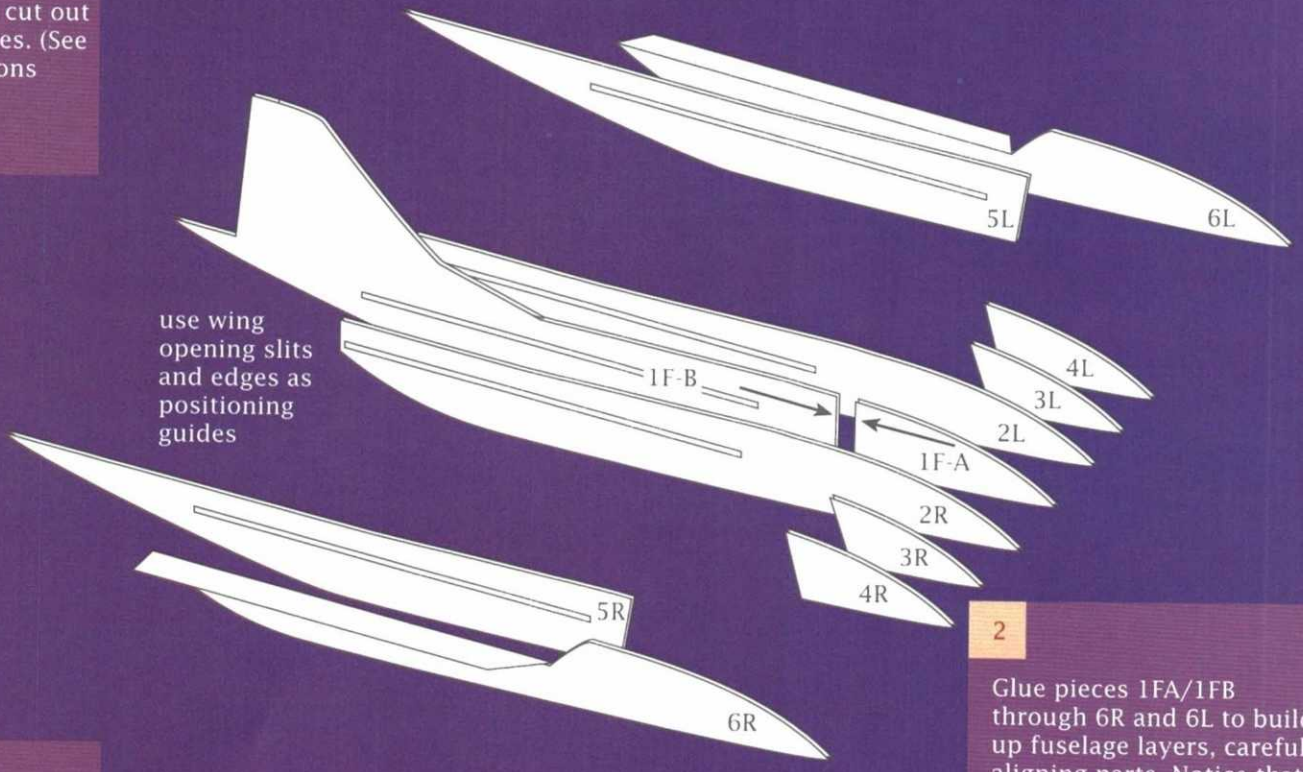


8

Building the Concorde

1

Photocopy the parts layouts for this model. Then cut out and prepare the pieces. (See the general instructions beginning on p 4.)

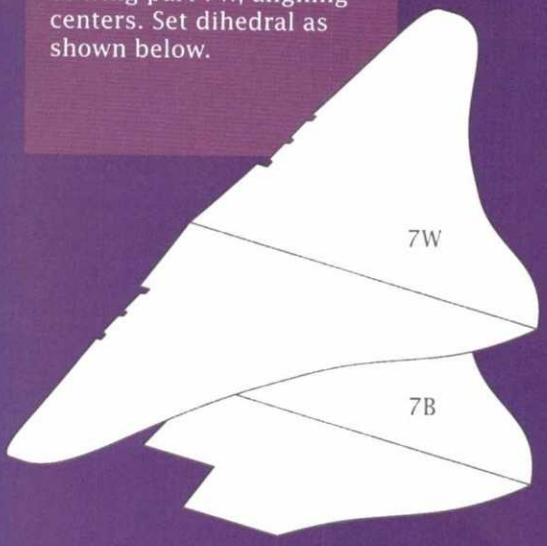


2

Glue pieces 1FA/1FB through 6R and 6L to build up fuselage layers, carefully aligning parts. Notice that the center fuselage piece consists of parts A & B.

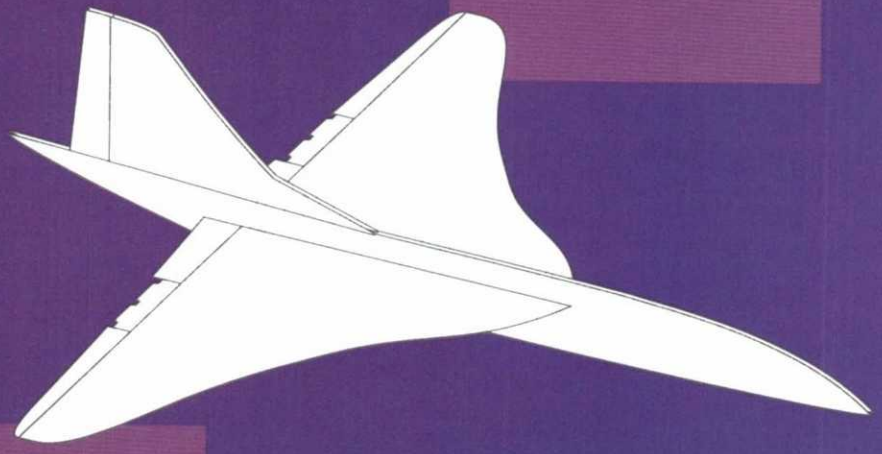
3

Glue piece 7B to the bottom of wing part 7W, aligning centers. Set dihedral as shown below.



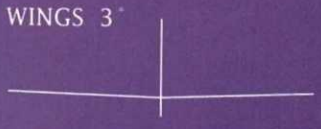
5

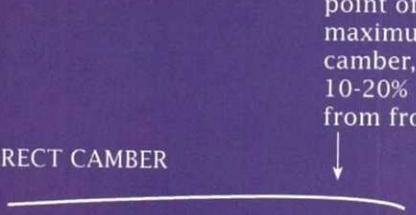
Camber the wings by curving the paper gently between thumb and forefinger. See below.



4

Applying glue to the wing tabs, fasten wing assembly to the fuselage, aligning center lines.





Meteor by flying 623 miles per hour and bringing the world speed record to the United States. The Shooting Star had a slender fuselage with thin tapered wings. The plane proved to be a very good design for subsonic flight and was developed into a jet trainer as the T-33 which, after 50 years, is still used in some countries.

The year 1947 was a breakthrough year. The American Douglas Skystreak exceeded the Shooting Star's record, pushing it to 650 miles per hour. That plane also exceeded the Vampire's altitude record by flying to 75,000 feet. Aircraft designers knew that Mach 1 was just around the corner.

For the next supersonic attempt the simple rocket engine was again called into service. The plane was the American Bell X-1. Its wings were not swept, but short, tapered, and very thin, a design thought to be suitable. Because the shape of the fuselage also determines airflow, this plane was shaped like a 50-calibre bullet, which was known to be stable at supersonic speed. Powered by a four-chamber rocket engine, the X-1 was carried to altitude in the bomb bay of a Boeing B-29 Superfortress, then released and fired up. After a number of flights into the dangerous transonic range, each faster than the one before, this plane attained 670 miles per hour at 42,000 feet, or Mach 1.2. It was a success. The date was October 14, 1947, one year after the ill fated Swallow attempt.

NOTE
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- Score lines in red.
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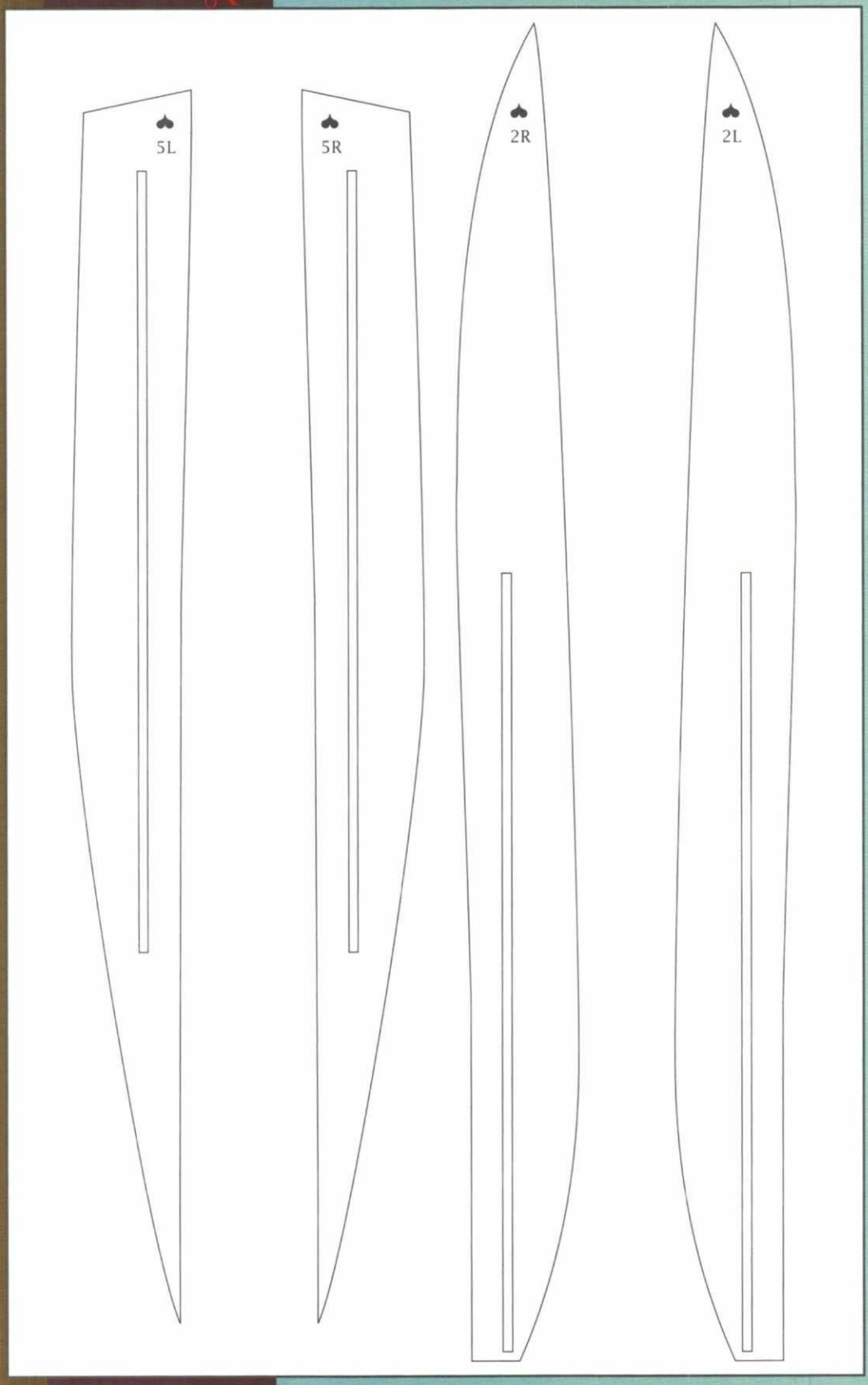
- ♠ Indicates the front edge of the piece.

NOTE
CUT OUT PHOTOCOPY ONLY

PARTS LAYOUT – Concorde



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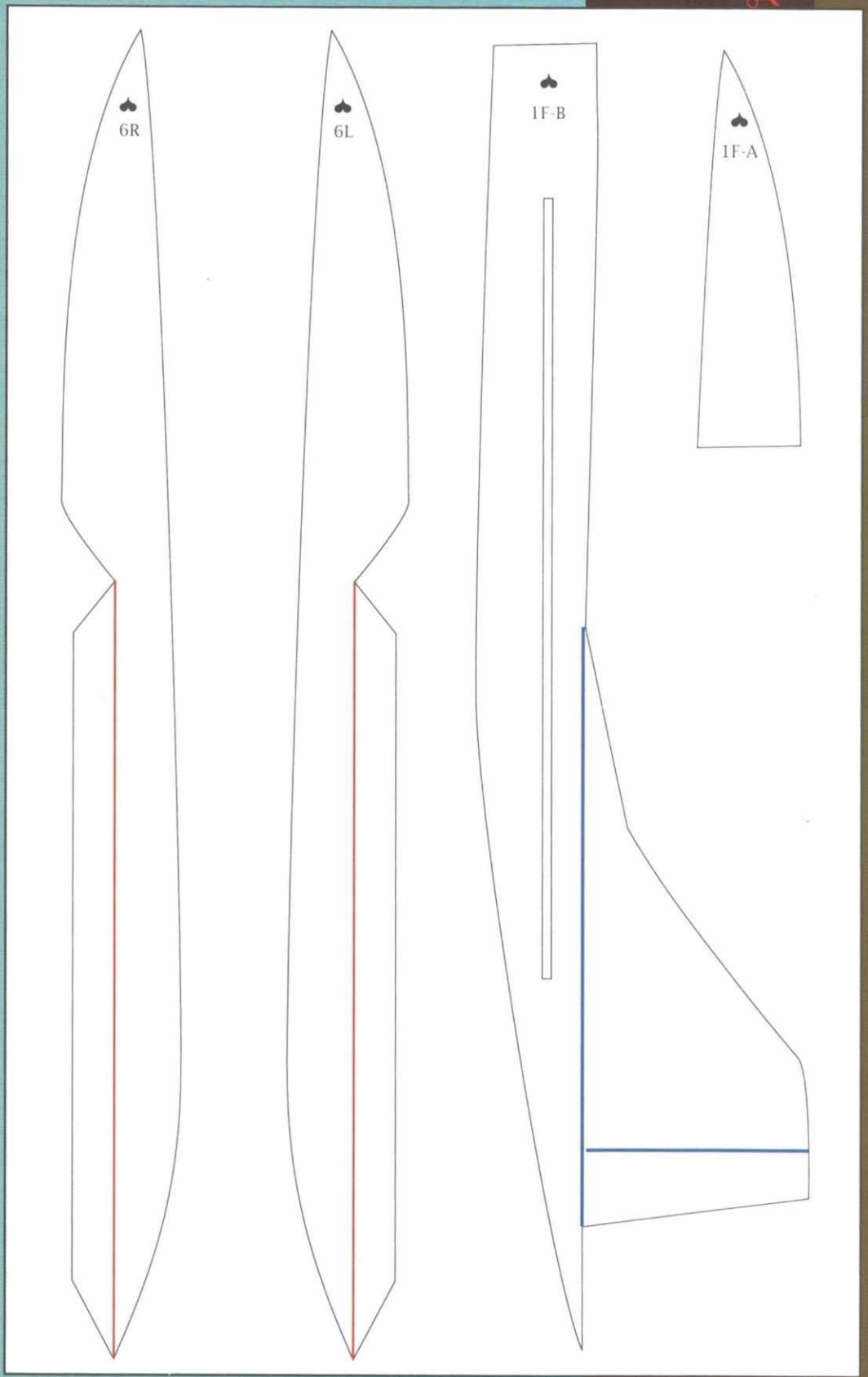
PARTS LAYOUT – Concorde



Research into wing sweepback continued by various airframe designers. North American Aviation took the lead in its development, but the Mikoyan-Gurevich company in Russia was close behind.

Russia had not actively developed jet propulsion during the war, but at war's end experimented by replacing the piston engine and propeller in a wartime Yak 3 with a captured German jet engine. Soon thereafter, in 1946, the Mikoyan-Gurevich company produced the first all-Russian jet, the MiG-9. **(#4, p 23.)** It was of conventional design without swept wings and subsonic, matching the Meteor in performance. But by 1950 this company had developed a swept wing supersonic machine, the MiG-15. In the Korean War it did battle with the American F-86 Sabre, with which it was closely matched. **(#5, p 28.)**

The swept wing F-86 Sabre and the MiG-15 had been in the planning stages when the Swallow crashed. In these planes the new handling problems of swept wings were identified and solved.

When the first model of the Sabre was released, also in 1947, it flew at just subsonic speed in level flight, and went supersonic successfully in a dive. Models produced from 1950 on were supersonic in level flight, although only in short bursts using an *after-*

burner (see p 76). This very successful airplane, the first supersonic fighter, was built in large numbers and remained in active service for the next twenty-five years in different countries. Many pilots said it was the best plane they ever flew.

The American X-1 experiments had proved that supersonic flight was a possibility, and the F-86 Sabre and the MiG-15 made it practical. In the meantime other countries, such as Italy and France, had also begun jet research, introducing successful models in the 1950s.

Jet propulsion changed the shape of the airplane through a very practical necessity, resulting in clean, gracefully swept lines of extraordinary beauty, exemplified first in the Sabrejet. Thereafter these lines, together with the futuristic whine of turbines and roar flames characterized a new generation of powered flight.

NOTE
- Cut on lines shown in black.
- Score lines in red.
- Use the blue lines as guides for adding details to the plane.
- ❥ Indicates the front edge of the piece.

NOTE
CUT OUT PHOTOCOPY ONLY

PARTS LAYOUT – Concorde